CONCRETE MIXTURES & REPORTS OF TESTS

I N D E X

EXPERIMENTS ON NEBRASKA PIT-RUN GRAVELS

INTRODUCTION.

As is well known to most of us many experiments have been performed by Prof. R. W. Crum of Iowa, and Prof. Duff Abrams of the Lewis Institute of Technology, on proportioning crushed stone, screened gravel and pit-run gravel in the designing of a concrete mixture. Prof. Crum has come to the conclusion that any gravel may be used in concrete provided the cement is varied with the sieve analysis of the gravel on hand. Therefore the engineering department of the City of Omaha has deemed it of value to experiment with Nebraska gravels in order to determine which sieve should be used as the dividing line between sand and gravel and then to determine what relative amounts of these would produce the best concrete. The experiments were conducted by the Omaha Testing Laboratories under the direction of Mr. A. C. Arend, City Engineer.

The experiments were divided into four series. In Series No. 1 the No. 10 sieve was used as the dividing line between the fine and coarse particles. Table No. 3 shows in what proportions the fine and coarse materials were mixed. The cement used with each mixture is also shown on the same table.

In series No. 2 and 3, the No. 8 and No. 4 sieves were used respectively to separate the pit-run gravel into fine and coarse. The mixtures are shown in table No. 4.

Series No. 4 consisted of five pit-run gravels, which were used without remixing in any way. In one of these gravels, we used more water than necessary and one of them was not as well graded as the rest. Table No. 5 gives the mixtures used.

For the first three series a pit-run gravel was separated and recombined in the proportion shown. The pit-run gravels used in the last series were obtained from local yards and represented several pits from which Omaha gets its supply.

The specific gravity, weight per cubic foot and voids were determined by the methods adopted by the American Society of Testing Materials. The voids were calculated from the weight per cubic foot and the specific gravity. In this connection we wished to check up a device which has been used by some laboratories. It consists of two cubical boxes arranged one above the other and connected by a rubber tube. The water from the upper box rises through the gravel in the lower box. When the water appears at the top of the gravel, the per cent of voids is read directly on a scale on the upper box. We found that for ordinary pit-run gravels the actual voids by this device checked very well with the theoretical, but with fine sands the results are low. That is due to the fact that the water rises so slowly that capillary action interferes with the displacing of the air bubbles. In any case this device tends to give low results.

The test pieces were made in cylindrical molds 4"x8". Enough water was used to produce a mortar which when piled into a cone, would flatten slowly. A tapered glass rod was used to rod the

concrete while the molds were filled. The molds were capped with glass plates.

The test pieces were made and stored in a room having a temperature of about 70 degrees F. They were removed from the molds 24 hours after they were made, weighed and immersed in water for 14 days, after which they remained in air till broken. The gravel used was air dried, the weight of a cubic foot of cement was taken as 94 pounds.

Only the 28 day compression test was made. Each value given in the tables is the average of three or more tests.

The Cement used passed all the tests.

THE RESULTS.

Table No. 1 shows the physical characteristics of the sand and gravel mixtures used. For convenient reference each mixture was given a number. Table No. 2 gives the characteristics of sand and gravels in general.

In table No. 1 we notice that the weights per cubic foot of gravel aggregates are unusually high. The results are accounted for by the fact that we used the aggregates in compact form. The so called loose volume method would not give uniform results.

The sieve analysis given in this table show that Nebraska pit-run gravels are graded fairly well. The amount passing the No. 100 sieve is less than 2%. The amount retained on the No. 4 sieve is about 35% of the amount retained on the No. 10 sieve.

In tables 3, 4 and 5 are tabulated the results of compression in pounds per square inch. With but two exceptions all mixtures where one part of cement to three parts aggregate was used the compression strength produced was more than 4000 pounds per square inch. As our testing machine did not register above 4167 pounds per square inch, all results above this figure are marked "plus".

The results indicate that the strength increases as the coarseness of the aggregate increases, but the increase is not marked until we reach a point where more than 50% of the aggregate is retained on the No. 10 screen. Theoretically the mixture in which the sand and gravel are in equal amounts should give the maximum strength, because this mixture has least voids but coarser mixtures actually do give more strength because they require less water.

In Table No. 5 we notice that two of the gravels gave comparatively low results. In one case, 4-B the gravel is not well graded and the other case, 4-D we used water in excess.

Curve B was constructed from series 1 and 4, table 3 and 5. These curves show quite clearly the relation between the material retained on the No. 10 sieve and the resulting compression strength. Curve C was constructed from series 2 and 3. It shows the relation between material retained on the No. 4 sieve and the resulting compression strength.

The results of these experiments indicate that to get the strongest concrete the aggregate should contain 50 to 60% of material retained on the No. 10 sieve, and that 15 to 25% of the entire aggregate should be retained on the No. 4 sieve.

In all the mixtures used in these experiments, we noticed that the weights per cubic foot of the green concrete were not as high as they should be theoretically. It occurred to us that the bulging effect of water on dry sand and gravel might furnish an explanation. Curve A shows the increase in volume caused by the addition of water to the dry aggregate. As was anticipated, a finer gravel bulges more than a coarse one with the same amount of water. Surface Tension is given as the cause. When enough water is added to thoroughly wet and cover the aggregate, the volume shows no increase. This fact was also anticipated because at this point, Surface Tension is reduced to a minimum and the particles move freely.

It is possible to approximate the amount of water in aggregate by visual inspection. If the particles appear damp the percent of water by weight is from 1 to 2; if damp and sticky, 2 to 5: if the water is visible in globules, 5 to 10; and if the water begins to separate, 10. Above 10 percent the water separates easily from the aggregate. The gravel as used on the work generally contains from a trace, to 7% of water.

From the above results it is easy to explain why the green concrete is not denser than is found by experience. If we take any pit-run gravel mixture and note the amounts of the various materials entering into a cubic foot of the green concrete, we find that the increase in volume is governed almost exactly by the bulging effect of water on the aggregate used. As an example take mixture A-6, from Series No. 1. In making this mixture we used a cubic foot of aggregate weighing 116.6 lbs., 14.5 lbs. cement and 13 lbs. of water. The total material used was 144 lbs. The volume of green concrete was 1.055 cubic foot. The green concrete weighed 136 lbs. per cubic foot. Therefore the increase in volume was 5.5% and since the aggregate had a voidage of 28% the decrease in volume should have been 11%. Therefore this mixture increased the volume by 16.5%. After allowing 20% of the water for the cement it leaves us an aggregate containing 8.7% water, which, according to the curve has a bulge of about 17%. Any other mixture may be figured in the same manner.

This shows to us that although it is desirable to use as little water as possible in making concrete, at the same time, we are producing a concrete which does not have the maximum weight per cubic foot.

It is also evident from the Curve A that the contractor who uses wet gravel by volume in proportioning concrete, is really using a richer cement mixture than he intends to. In case of a fine pit-run gravel, where the specifications call for 1 to 5 mixture the contractor will actually produce about a 1 to 4 mixture if he uses wet material.

ABLE No. 1. PHYSICAL CHARACTERISTICS OF AGGREGATES -

ERIES	MIXTURE	NUMBER	% VOIDS	WEIGHT PER CU. FT.	SPECIFIC GRAVITY	P.100	R.100	R.50	R.30	R.10	R.8	R.4
1-A	80 - 20	1	28.05	116.65	2.60	2.48	97.52	63.13	48.0	20.0		6.08
1-B	70 - 30	2	27.33	117.81	2.60	2.17	97.83	85.28	72.0	30.0		9.12
1-C	60 - 40	3	27.18	118.05	2.60	1.86	98.14	87.38	76.0	40.0		12.16
1-D	50 - 50	4	24.99	121.60	2.60	1.55	98.45	89.48	80.0	50.0		15.20
1-E	40 - 60	5	26.79	118.69	2.60	1.24	98.76	91.59	84.0	60.0		18.24
2-A	85 - 15	6	26.44	119.25	2.60	2.34	97.66	81.13	72.2	28.6	15.0	6.10
2-B	75 - 25	7	26.84	118.61	2.60	2.06	97.94	83.35	75.47	37.0	25.0	10.16
2-C	65 - 35	8	26.59	119.00	2.60	1.79	98.21	85.57	78.74	45.4	35.0	14.2
3-A	90 - 10	9	24.92	121.72	2.60	1.95	98.05	88.57	79.66	43.3		10.0
3-B	[illegible] - 20	10	24.07	123.10	2.60	1.74	98.26	89.84	81.92	49.6		20.0
3-C	70 - 30	11	25.43	120.79	2.60	1.52	98.48	91.11	84.18	55.9		30.0
4-A	PLATTE RIVER	12	28.49	119.10	2.67	1.00	99.00	91.10	83.20	48.0		13.4
4-B	"	13	30.09	113.47	2.60	1.25	98.75	96.35	93.60	59.3		14.9
4-C	"	14	27.84	118.33	2.63	2.00	98.00	89.90	77.65	35.5		8.2
4-D	"	15	26.45	120.61	2.63	3.60	96.40	78.00	61.75	26.1		7.9
4-E	"	16	29.57	117.26	2.67	0.75	99.25	94.40	89.20	51.2		15.8

ABLE No. 3 ERIES No. 1 COMPRESSION STRENGTHS AT END OF 28 DAYS.

GRAVEL NUMBER	SUBDIVISION OF SERIES	AGGREGATE BY WEIGHT			BY WEIGHT			BY VOLUME CEMENT TO AGGREGATE	BY WEIGHT % WATER TO AGGREGATE	WT. PER CU. FT. OF FINE AND COARSE AGG.	WT. PER CU. FT GREEN CONCRETE.	COMPRESSI STRENGT LBS. PER SQ.
		P.10	P.8	P.4	R.10	R.8	R.4					
1	1-A-3	80			20			1 TO 3	9.34	116.65	140.40	4167+
1	1-A-4	80			20			1 TO 4	11.11	116.65	139.32	2610
1	1-A-5	80			20			1 TO 5	10.73	116.65	135.08	2105
1	1-A-6	80			20			1 TO 6	10.24	116.65	137.16	1660
2	1-B-3	70			30			1 TO 3	9.12	117.81	142.56	4167+
2	1-B-4	70			30			1 TO 4	10.00	117.81	140.40	2750
2	1-B-5	70			30			1 TO 5	10.00	117.81	138.24	2200
2	1-B-6	70			30			1 TO 6	10.35	117.81	135.08	1700
3	1-C-3	60			40			1 TO 3	10.00	118.05	142.56	4167
3	1-C-4	60			40			1 TO 4	9.52	118.05	141.48	2904
3	1-C-5	60			40			1 TO 5	9.58	118.05	140.40	2260
3	1-C-6	60			40			1 TO 6	10.00	118.05	139.32	1760
4	1-D-3	50			50			1 TO 3	9.12	121.60	146.88	4167+
4	1-D-4	50			50			1 TO 4	9.33	121.60	145.26	3070
4	1-D-5	50			50			1 TO 5	8.85	121.60	142.56	2428
4	1-D-6	50			50			1 TO 6	8.85	121.60	140.40	1600
5	1-E-3	40			60			1 TO 3	8.42	118.69	147.96	4167
5	1-E-4	40			60			1 TO 4	8.33	118.69	145.80	3805
5	1-E-5	40			60			1 TO 5	8.27	118.69	144.72	2920
5	1-E-6	40			60			1 TO 6	8.24	118.69	141.48	2375

TESTS BY OMAHA TESTING LABORATORIES UNDER DIRECTION A.C. AREND, CITY ENGR. COMPLETED MAR. 15, 1921.

Table No. 2.

GENERAL CHARACTERISTICS OF SANDS & GRAVEL			
GRADING	WT. PER CU. FT.	VOIDS	SP. GR.
PASS 10-100% PASS 100-3.17%	112.13	32.14	2.60
RET. 10-100% PASS 2-100%	104.30	35.60	2.60
PASS 8-100% PASS 100-2.75%	113.02	30.30	2.60
RET. 8-100% PASS 2-100%	106.30	35.00	2.60
PASS 4-100% PASS 100-2.17%	117.32	28.46	2.60
RET. 4-100% PASS 2-100%	103.00	37.25	2.60

TABLE NO 4 SERIES NO 2.

COMPRESSION STRENGTHS AT END OF 28 DAYS.

GRAVEL NUMBER	SUBDIVISION OF SERIES	AGGREGATE						BY VOLUME CEMENT TO AGGREGATE	BY WEIGHT PERCENT WATER TO AGGREGATE	WT. PER CU. FT. OF FINE AND COARSE AGGREGATE	WT. PER CU. FT. GREEN CONCRETE	COMPRESSION STRENGTH LBS. PER SQ. INCH.
		BY WEIGHT			BY WEIGHT							
		P. 10	P. 8	P. 4	R. 10	R. 8	R. 4					
6	2-A		85			15		1 TO 4	9.6	119.25	140.94	3201
7	2-B		75			25		1 TO 4	9.8	118.61	140.94	3291
8	2-C		65			35		1 TO 4	9.8	119.00	142.56	3400
SERIES NO 3.												
9	3-A			90			10	1 TO 4	9.7	121.72	142.0	3285
10	3-B			80			20	1 TO 4	9.1	123.10	145.8	3620
11	3-C			70			30	1 TO 4	9.3	120.79	145.8	4138

TABLE NO 5 SERIES NO 4.

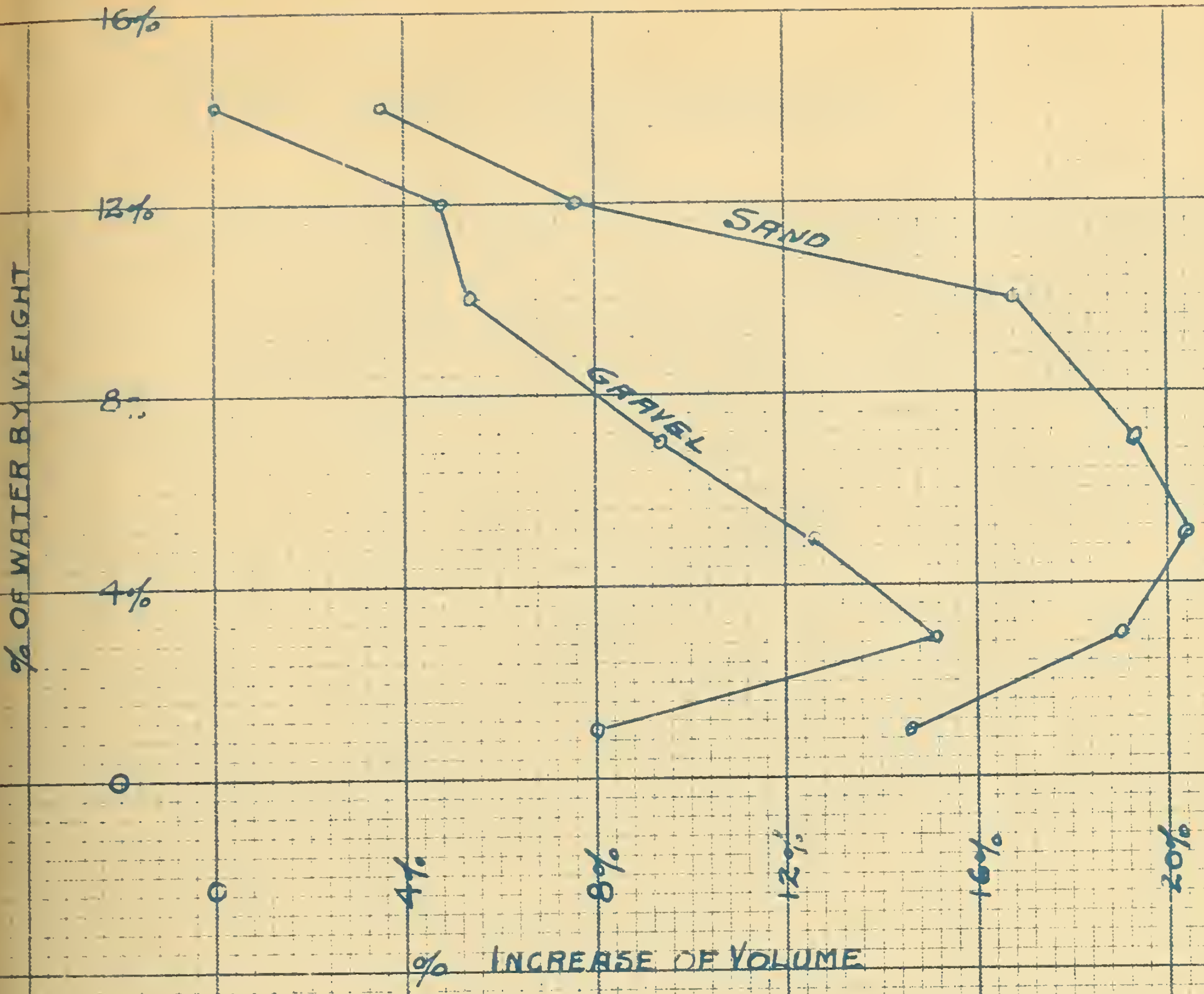
COMPRESSION STRENGTHS AT END OF 28 DAYS

GRAVEL NUMBER	PITS	SUBDIVISION OF SERIES	BY VOLUME CEMENT TO AGGREGATE	BY WEIGHT % OF WATER TO AGGREGATE	WT. PER CU. FT. OF FINE & COARSE AGGREGATE	WT. PER CU. FT. OF GREEN CONCRETE	COMPRESSION STRENGTH
12	PLATTE RIVER	4-A-3	1 TO 3	9.3	119.1	145.80	4167 +
12	"	4-A-4	1 TO 4	9.1	119.1	142.56	3333
12	"	4-A-5	1 TO 5	8.85	119.1	143.64	2546
12	"	4-A-6	1 TO 6	8.82	119.1	142.56	2046
13	"	4-B-3 (SEE INTROD.)	1 TO 3	9.5	113.47	147.51	3700
13	"	4-B-4	1 TO 4	9.4	113.47	144.66	2300
13	"	4-B-5	1 TO 5	8.8	113.47	139.32	2000
13	"	4-B-6	1 TO 6	8.5	113.47	136.71	1638
14	"	4-C-3	1 TO 3	10.0	118.33	139.95	4000
14	"	4-C-4	1 TO 4	10.0	118.33	137.63	2950
14	"	4-C-5	1 TO 5	9.5	118.33	135.[illegible]2	2300
14	"	4-C-6	1 TO 6	9.7	118.33	135.08	1780
15	"	4-D-3 (SEE INTROD.)	1 TO 3	11.8	120.61	138.78	3313
15	"	4-D-4	1 TO 4	11.9 WET	120.61	135.08	1533
15	"	4-D-5	1 TO 5	11.5	120.61	135.08	1230
15	"	4-D-6	1 TO 6	11.7	120.61	134.00	712
16	"	4-E-3	1 TO 3	11.5	117.26	142.56	4167 +
16	"	4-E-4	1 TO 4	10.5	117.26	142.56	3000
16	"	4-E-5	1 TO 5	10.4	117.26	140.94	2680
16	"	4-E-6	1 TO 6	[illegible]	117.26	135.08	1750

TESTS BY OMAHA TESTING LABORATORIES UNDER DIRECTION A.C. AREND, CITY ENGR. OMAHA. 3-15-21

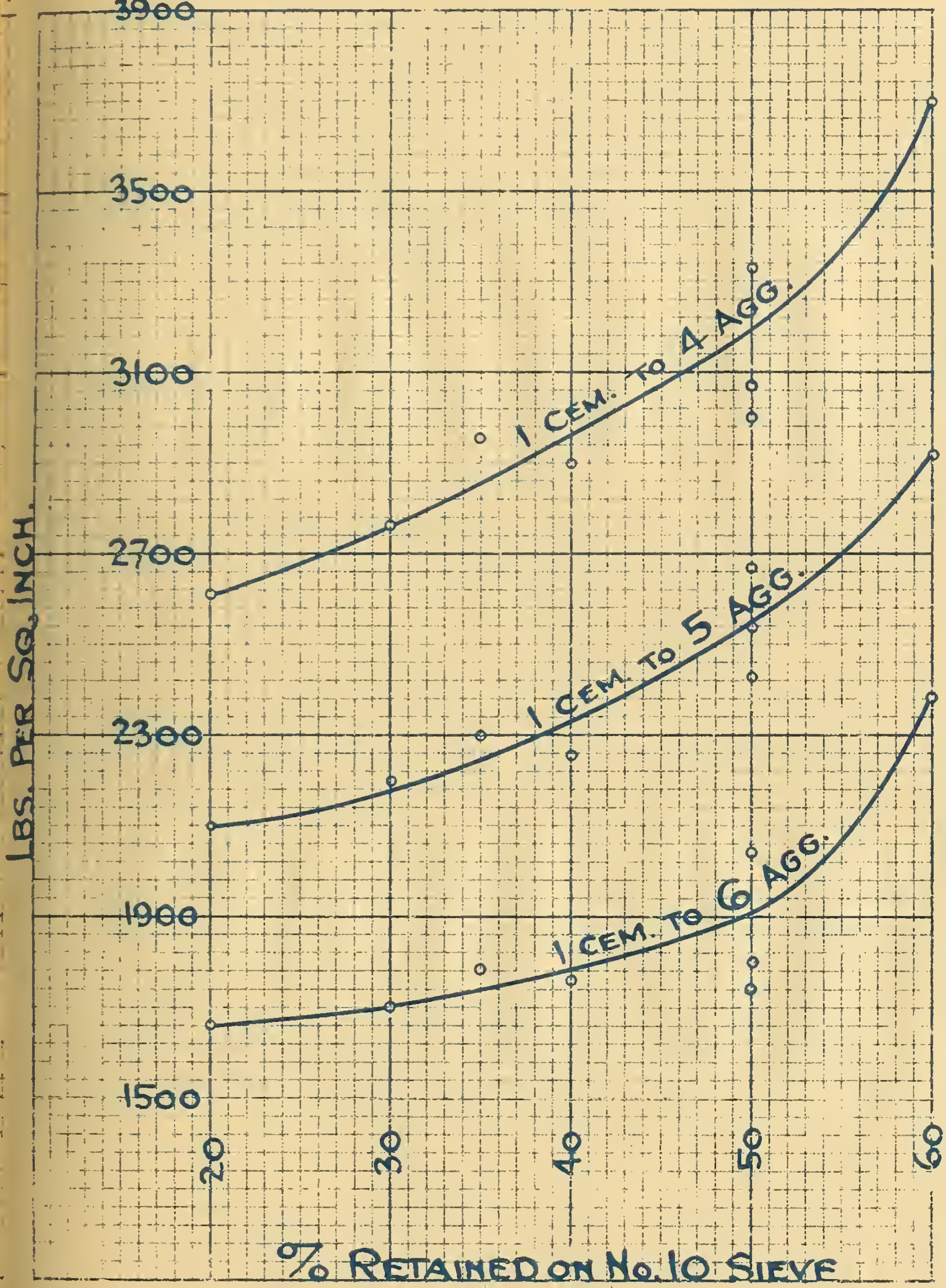
THE BULGING EFFECT OF WATER ON SAND & GRAVEL.

"A"



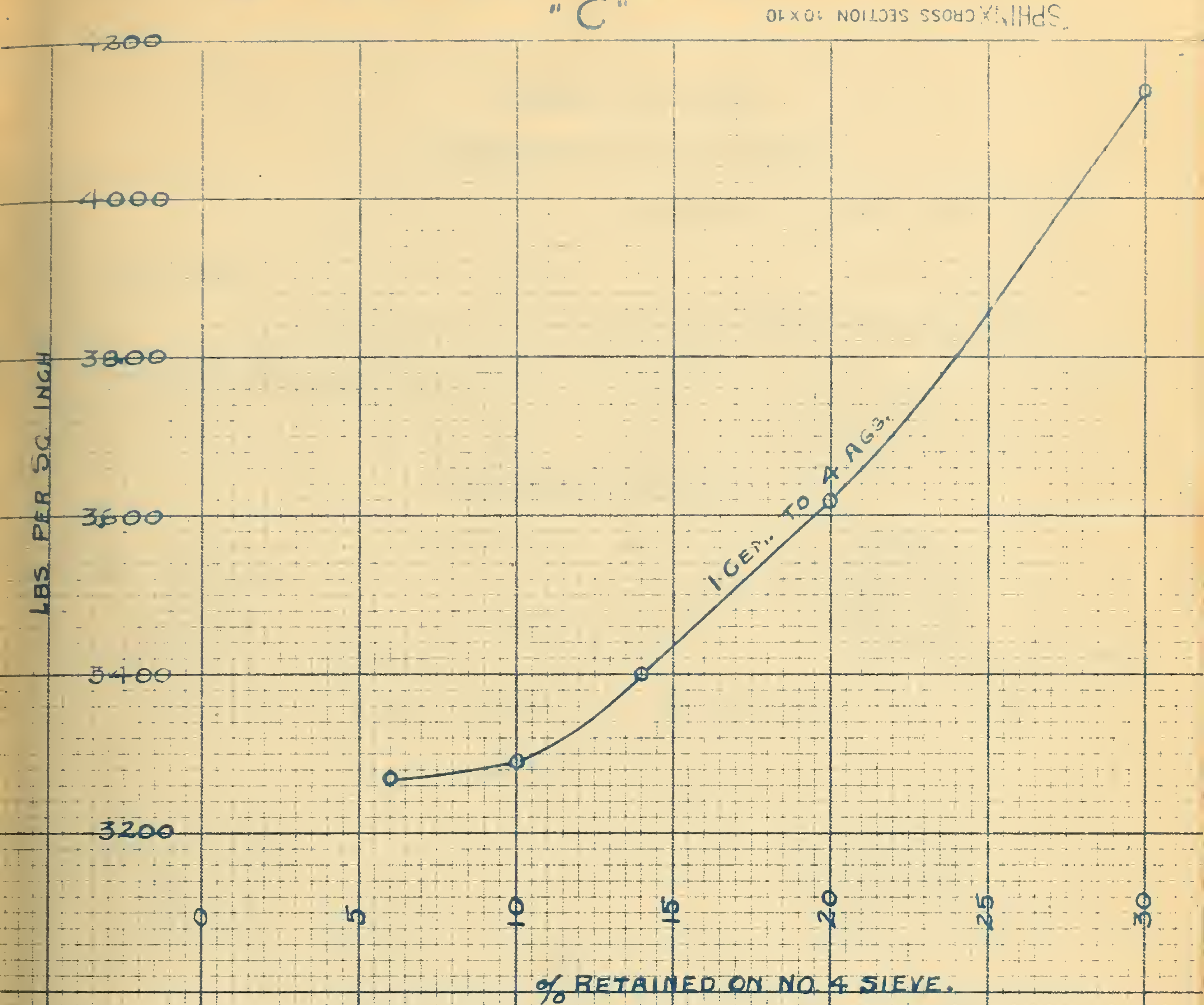
TESTS BY OMAHA TESTING LABORATORIES
UNDER DIRECTION OF A.C. AREND, CITY ENGR.
OMAHA, NEBR. COMPLETED MAR. 15, 1921.

CURVES MADE FROM SERIES No. 1 & 4.
"B".



CURVE MADE FROM SERIES NO. 2 & 3

"C"



TESTS MADE BY OMAHA TESTING LABORATORIES
UNDER DIRECTION OF A.C. AREND, CITY ENGR. OMAHA
NEBR. COMPLETED MAR. 15, 1921.

MODJESKI & ANGIER

INSPECTING CIVIL ENGINEERS.

Chicago, Ill. Aug. 19, 1915.

Gentlemen:

We are pleased to hand you herewith results of our twenty eight day tests on concrete materials for the World Herald Building, Omaha, Nebr.,

Mix 1:2:4   Dewey Cement, Platte River Sand & Crushed Stone

Compressive Strength

7 Days Per Sq. Inch		28 Days Per Sq. Inch	
1480 Lbs		1790 Lbs	
1630 Lbs		2090 Lbs	
1555 Lbs	Average	1940 Lbs	Average

Mix 1:4   Dewey Cement   Sand-Gravel

Compressive Strength

7 Days Per Sq. Inch		28 Days Per Sq. Inch	
1940 Lbs		3100 Lbs	
2050 Lbs		2850 Lbs	
1995 Lbs	Average	2975	Average

The figures given above are conclusive evidence that your sand-gravel mixture is superior for concrete purposes to the Platte River sand with crushed stone mixture; confirming our opinion expressed in seven days report.

Yours very truly,

MODJESKI & ANGIER

(Signed) J. J. Reeves, Mgr.

UNITED STATES DEPARTMENT OF AGRICULTURE.

BUREAU OF PUBLIC ROADS.

Washington, D.C.

June 23, 1919.

REPORT ON SAMPLE OF SAND-GRAVEL

Laboratory No. 14418
Name of Material, SAND-GRAVEL
Identification marks, 1930495 & 96 ON BAGS.
SUBMITTED BY LYMAN-RICHEY SAND CO., FREMONT, NEBR.
Sampled June 9, 1919 Received June 13th, 1919.
Sampled from CAR.
Quantity represented, 360 ACRES, 30 FEET DEEP.
Source of material, Fremont, Dodge County, Nebraska.
Location used or to be used, NEBRASKA FEDERAL AID PROJECT NO. 81.
Examined for USE IN WEARING COURSE, ONE-COURSE CONCRETE PAVEMENT.

TEST RESULTS

SAND (Mechanical Analysis)		GRAVEL (Mechanical Analysis)	
action	%	Fraction	%
tained on 1/4" screen	14.7	Passing 3/4" retained on 1/2"	2.0
ssing 1/4" retained 1 10 Mesh.	44.4	Passing 1/2" retained on 1/4"	12.7
ssing 10 retained on 20 Mesh	27.9	Passing 1/4" screen	85.3
ssing 20 retained on 30 "	5.5		
ssing 30 retained on 40 "	3.1		
ssing 40 retained on 50 "	1.3		
ssing 50 retained on 80 "	1.9		
ssing 80 retained on 100 "	0.2		
assing 100 retained on 200 "	0.5		
assing 200 Mesh	0.5		
Total	100.0	Total	100.

Loss by washing (Silt & Clay) 0.4%

Character of material:
Sample consists essentially of rounded fragments of granite, quartz and quartzite with a large amount of sub-angular quartz sand.

(Signed)
P. W. J. Milson
Acting Director.

UNITED STATES DEPARTMENT OF AGRICULTURE.

BUREAU OF PUBLIC ROADS.

Washington, D.C.

June 23, 1919.

Laboratory No. 14418
Name--SAND-GRAVEL
Identification marks, 1930495 & 96 ON BAGS.
SUBMITTED BY LYMAN-RICHEY SAND CO., FREMONT, NEBR.
Sampled June 9, 1919 Received June 13th, 1919.
Sampled from CAR.
Quantity represented, 360 ACRES, 30 FEET DEEP.
Source of material, Fremont, Dodge County, Nebraska.
Location used or to be used, NEBRASKA FEDERAL AID PROJECT NO. 81.
Examined for USE IN WEARING COURSE, CEMENT CONCRETE PAVEMENT.

TEST RESULTS

Crushing strength, 6" x 12" cylinders, age 7 days.

Total Load, Lbs.			Unit Load, Lbs. per square inch		
A	B		A	B	
58350	57780		2065	2040	
65940	58180		2330	2060	
62145	57980	Average	2198	2050	Average

A- Proportion by volume (1 part cement
(3 parts No. 14418 (Sand-gravel)

B- Proportions by volume (1 part cement) Accepted
(1½ parts Potomac River Sand) as
(3 parts Potomac River Gravel) Standard

(Signed) P. W. J. Milson
Acting Director.

C O P Y

STATE of NEBRASKA
Samuel R. McKelvie, Governor
LINCOLN

February 14, 1921.

Lyman-Richey Sand Co.,

Omaha, Nebr.

Attention: L. C. Curtis.

Gentlemen:

In reply to your letter of February 10th. asking for the average of the compression tests made on the concrete used in the concrete pavement of Project 58-A Schuyler-Platte River, you will find herewith table stating the average of the 28 day tests for the various months.

Month	1:3 Mix Average Compressive Strength
June	3472
July	3115
August	3733

Yours very truly,

Clark E. Mickey

Consulting & Testing Engineer.

CEM:FP.

C O P Y

STATE of NEBRASKA
Samuel R. McKelvie, Governor
LINCOLN

February 14, 1921.

Lyman-Richey Sand Co.,

Omaha, Nebr.

Attention: L. C. Curtis.

Gentlemen:

In reply to your letter of February 10th. asking for the average of the compression tests made on the concrete used in the concrete pavement of Project 81, from Fremont to Ames, you will find herewith table stating the average of the 28 day tests for the various months.

Month	1:3 Mix Average Compressive Strength
May	3464
June	3589
July	3644
September	3130

Yours very truly,

Clark E. Mickey

Consulting & Testing Engineer.

CEM:FP.

OFFICE OF OMAHA CITY ENGINEER

TESTS BY OMAHA TESTING LABORATORIES AUGUST 1919

Voids

Omaha test (3 samples) (28.33)
Omaha test (3 samples) (25.52) Average 26.92.

Silt Tests.

From 0.9% to 2.78% volume measure. (Allowable, 7% by volume.)

Colorimetric Test.

Practically clear in each test. Hence free from organic matter.

Crushing Tests
8x8x16 Cylinders
Ends set in Plaster of Paris.

Cement	Sand-Gravel	7da. # sq.in.	28da. # sq.in.	105da. # sq.in.
1-3	Extra Strong	3187	4260	4516
1-3½	For Concrete Paving	2300	3497	4500
1-4	For Heavy Sidewalks Heavy Walls	1866	2974	3800
1-5	For Heavy Traffic Paving Base	1048	2482	3037
1-6	For Light Traffic Paving Base	554	1347	2003

W. H. Campen, Manager.

THE OMAHA TESTING LABORATORIES, INC.

OMAHA, NEBR., Sept. 15th, 1921.

RELATIVE STRENGTH OF CONCRETE MADE FROM NEBRASKA CRUSHED LIMESTONE AND SAND GRAVEL.

By W. H. Campen

These experiments were conducted to study the concrete made using limestone in one case and sand-gravel in the other. The object in view was to determine the strengths produced by both kinds of concrete, and also to observe the yields. A number of Nebraska Civil Engineers engaged in paving work give the contractors the option of using one part cement, two and one-half parts sand and five parts crushed stone by volume or one part cement to five parts sand-gravel by volume. The main part of our experiments consisted of determining whether or not the mixtures were actually equal in strength.

We selected two ordinary crushed limestones, one from the Louisville quarry and the other from the Weeping Water quarry. The sand-gravel used was taken from a pile in Omaha and was being used for the construction of concrete base. The sand-gravel had been shipped from the Fremont pit. The stone weighed 90 lbs per cubic foot and contained 47% voids. The sand-gravel weighed 101 lbs. per cubic foot (loose volume) and contained 25% voids. Its screen analysis was as follows: Retained on a #10 screen, 56%; retained on a #4 screen, 14%; passing a #100 screen, 1%; Tested cement was used.

The actual experiments consisted of making test cylinders 4" x 8", of 1 to 5, 1 to 5½ and 1 to 6, using sand-gravel, and of 1 to 2½ to 5 using the two limestones. Six test pieces were made of each mixture and these were broken at the end of 7 and 28 days.

As the sand-gravel is often used in a damp condition, test pieces were made from material to which water had been added before proportioning.

The results of the experiments are shown in the following table:

Material used:	Mixture:	Volume yield: concrete	Wt. Green concrete per cu. ft.	Compression lbs per sq. in. 7 das.	28 das.
Sand gravel (dry)	1 cement 5 sand gr	no change	143	788	2128
Sand gravel (dry)	1 cement 5½ sand gr	no change	142	990	1833
Sand gravel (dry)	1 cement 6 sand gr	no change	141	500	1168
Sand gravel (wet)	1 cement 5 sand gr	16% decrease	141	902	2310
Sand gravel (wet)	1 cement 5½ sand gr	16% decrease	141	767	2011

continued:

Material used:	Mixture:	Volume yield: concrete	Wt.Green concrete per cu. ft.	Compression lbs per sq.in. 7 das.	28 das.
Sand gravel (wet)	1 cement 6 sand gr	16% decrease	140	517	1342
Louisville limestone	1 cement $2\frac{1}{2}$ sand 5 stone	10% increase	150	644	1416
Weeping Water limestone	1 cement $2\frac{1}{2}$ sand 5 stone	10% increase	150	565	1038

The results as anticipated by the author show two distinct features; viz, damp sand-gravel decreases the concrete yield by 16% computed on the volume of sand-gravel taken and the compression strength is greater than the corresponding mixture in which dry gravel was used. The volume shrinkage shows that a 1 to 5 mixture using damp gravel gives a concrete containing about 24% cement.

From the above data it is evident that to obtain a concrete equivalent in strength to a 1, $2\frac{1}{2}$, 5 stone mixture one may use a 1 to $5\frac{1}{2}$ or even a 1 to 6 gravel mixture.

COMPARISON OF TESTS

1:2:4--Stone Mix28 days

Modkeski & Angier, Chicago, 1915			1940#

1:2½:5--Stone Mix

Omaha Testing Laboratories, 1921	1416		
	1038	Average	1227#

1:4 Sand-gravel

Modjeski & Angier, Chicago, 1915	2975#		
Omaha City Engineer 1915-6	2974#		
Omaha Testing Laboratories, 1921	3070#	Average	3006#

1:5 Sand-gravel

Omaha City Engineer, 1915	2482#		
Omaha Testing Laboratories, 1921	2428#	Average	2455#

1:5½ Sand-gravel

Omaha Testing Laboratories, 1921	2011#		

1:6 Sand-gravel

Omaha Testing Laboratories, 1921	1342#		
	1760#		
	1800#		
	2375#	Average	1804#

1:4 Sand-gravel mix shows over 1000# greater strength than 1:2:4 Stone mix.

1:5 Sand-gravel mix shows over 1200# greater strength than 1:2½:5 Stone mix and over 500# more than 1:2:4 Stone mix.

1:5½ Sand-gravel shows nearly 800# greater strength than 1:2½:5 Stone mix and to be slightly stronger, or equal to 1:2:4 Stone mix.

1:6 Sand-gravel shows nearly 600# more strength than 1:2½:5 Stone mix and within 200# as great strength as 1:2:4 Stone mix.

WESTERN LABORATORIES
Consulting And Testing Engineers
132 North 12th Street
LINCOLN, NEBR.

November 15, 1921.

Mr. L. C. Curtis,
General Sales Manager,
Lyman-Richey Sand Company,
Omaha, Nebraska.

Dear Sir:-

In compliance with your recent request I wish to submit the following brief summary of the purposes of the investigations of concrete we are now conducting and the information which should be obtained from these investigations.

The purpose of these investigations is to determine the physical properties of concrete that is actually being produced for concrete pavement foundations by the use of Nebraska gravel containing various proportions of material retained on the 10-mesh sieve.

A large proportion of the determinations will be made upon samples that are prepared under actual working conditions which are common to concrete pavement base construction. A part of the samples being made under working conditions are being molded on the street on paving jobs at the time of construction. When taking these samples all the details of construction are left exactly as is common for this class of work and the samples are molded after the concrete is deposited on the subgrade and graded. These samples are molded in such a way that they are truly representative of the condition of the concrete in the base, that is the material is not tamped in the mold but simply placed within the cylinder and a thin strip passed round the inside of the mold to flush the material to the surface so that the outside of the sample is no more porous than other parts.

Other samples will be molded to the same consistency in the laboratory. The laboratory samples will be tested to determine their compressive strength, modulus of elasticity, coefficient of expansion and expansion due to water absorption. The purpose of the last group of tests is to determine the stress produced in the base due to changes in temperature and changes in moisture content when varying proportions of cement are used in the mixture. From the information thus obtained it will be possible to determine whether a mixture can be used which will have the proper compressive strength to withstand the stress produced by expansion and thus eliminate all heaving and crushing of the concrete base from that cause.

It is a fact that the modulus of elasticity of concrete varies with the proportions of the mixture, the modulus increasing with an increase in the cement content while the coefficient of expansion seems to be oractically the same for all mixtures. This being the case it may develop that a better concrete foundation for pavements may be produced by reducing the cement content of the mixture and thus reducing the modulus of elasticity which will in turn reduce the stress produced by changes in temperature. The compressive strength will necessarily be reduced but may still be great enough to withstand this stress. On the other hand the compressive strength may also be increased by changing the amount of material retained on the 10-mesh sieve to some other proportion than is now in common use.

It is doubtless true that the proportion of aggregate retained on the 10-mesh sieve should be varied for the various proportions of cement in order to produce the best concrete possible for that mixture. As an illustration, if the best results may be produced in a 1:3 mixture having fifty per cent of the aggregate retained on the 10-mesh sieve it is practically a certainty that such a proportion of aggregate retained on a 10-mesh sieve will not give the greatest strength in a 1:6 mixture. When these investigations are completed it should be possible to state what the proportion of aggregate retained on the 10-mesh sieve should be to produce maximum strength for the various proportions of cement and aggregate under actual concrete foundation construction conditions.

Information on the 28-day strength tests on a 1:5 mixture laid for a pavement foundation should be complete by January 1, 1922 while the laboratory investigations on various mixtures, prepared as outlined above, should be completed by April 1, 1922, including 28-day strength tests, determinations of modulus of elasticity and determinations of coefficient of expansion.

Other information incidental to these investigations will be obtained as progress is being made and will also be forwarded to you.

Yours truly,

WESTERN LABORATORIES,

By Roy M. Green, Mgr.

A DISCUSSION OF THE CONCRETE YIELD FOR VARIOUS COMBINATIONS OF NEBRASKA SANDS AND GRAVELS.

By
Roy M. Green,
Manager, Western Laboratories,
132 North 12th St.,
Lincoln, Nebraska.

PURPOSE OF DISCUSSION. The purpose of this discussion is to show the effect of different amounts of moisture upon the volume of combinations of Nebraska sands and gravels and to show the concrete yields for these materials when measured by different methods and while containing various percentages of moisture. The weight of the aggregate necessary to produce one cubic foot of concrete from these materials will also be shown as well as the quantity used in making concrete of one inch Nebraska limestone and pit-run sand.

METHOD OF MAKING DETERMINATIONS OF WEIGHT PER CUBIC FOOT OF AGGREGATE. The method of making determinations of the unit weight of aggregate was the standard of the American Society for Testing Materials, C-20-21.

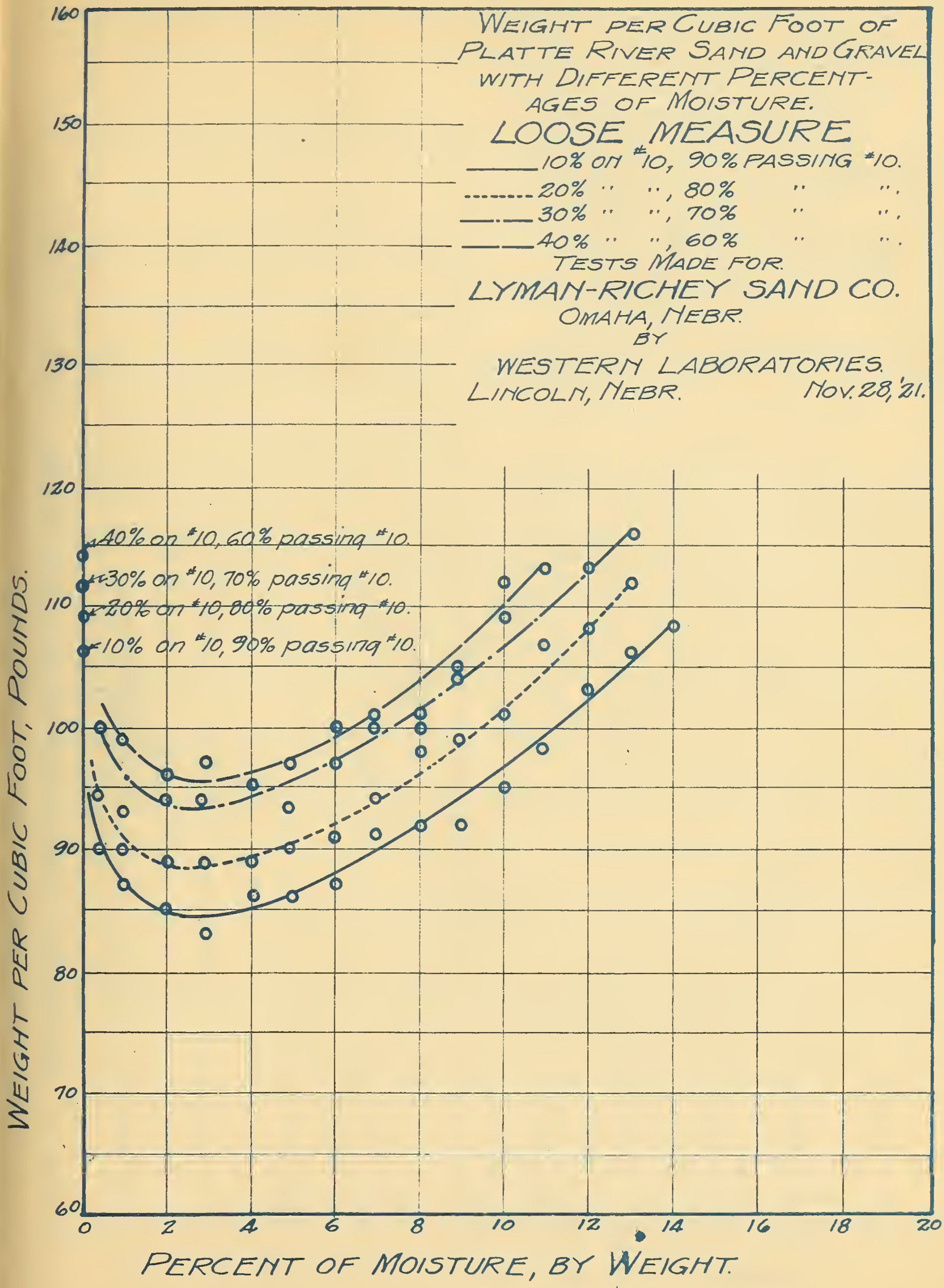
The equipment for this determination consists of a balance, cylindrical container 10-inches in diameter by 11-inches high, and a metal rod 3/4-inch in diameter and 18-inches long, tapered to a blunt point.

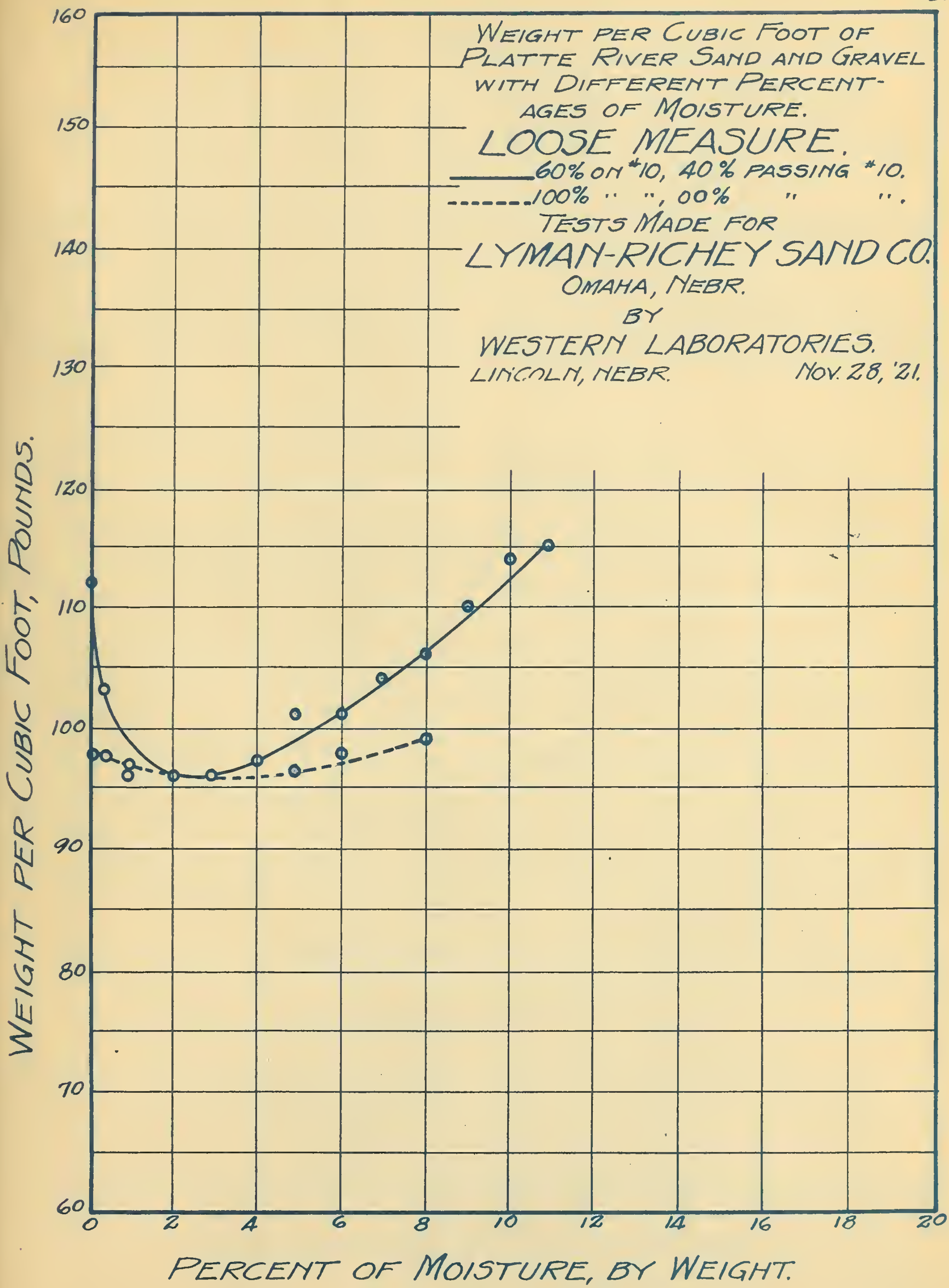
The cylinder is first calibrated by weighing it empty, then repeating the weight with the container filled with water. The test is made by introducing enough aggregate into the cylinder to fill it one-third full. The material is then tamped with the rod twenty-five times and more material added until the container is two-thirds full. The tamping is then repeated, allowing the tamper to go only as far into the material as the depth of the second layer. The cylinder is then heaped full and the tamping process repeated. The excess material is then struck off the top of the cylinder with the rod and the whole is weighed. From this data the weight per cubic foot of the material is determined.

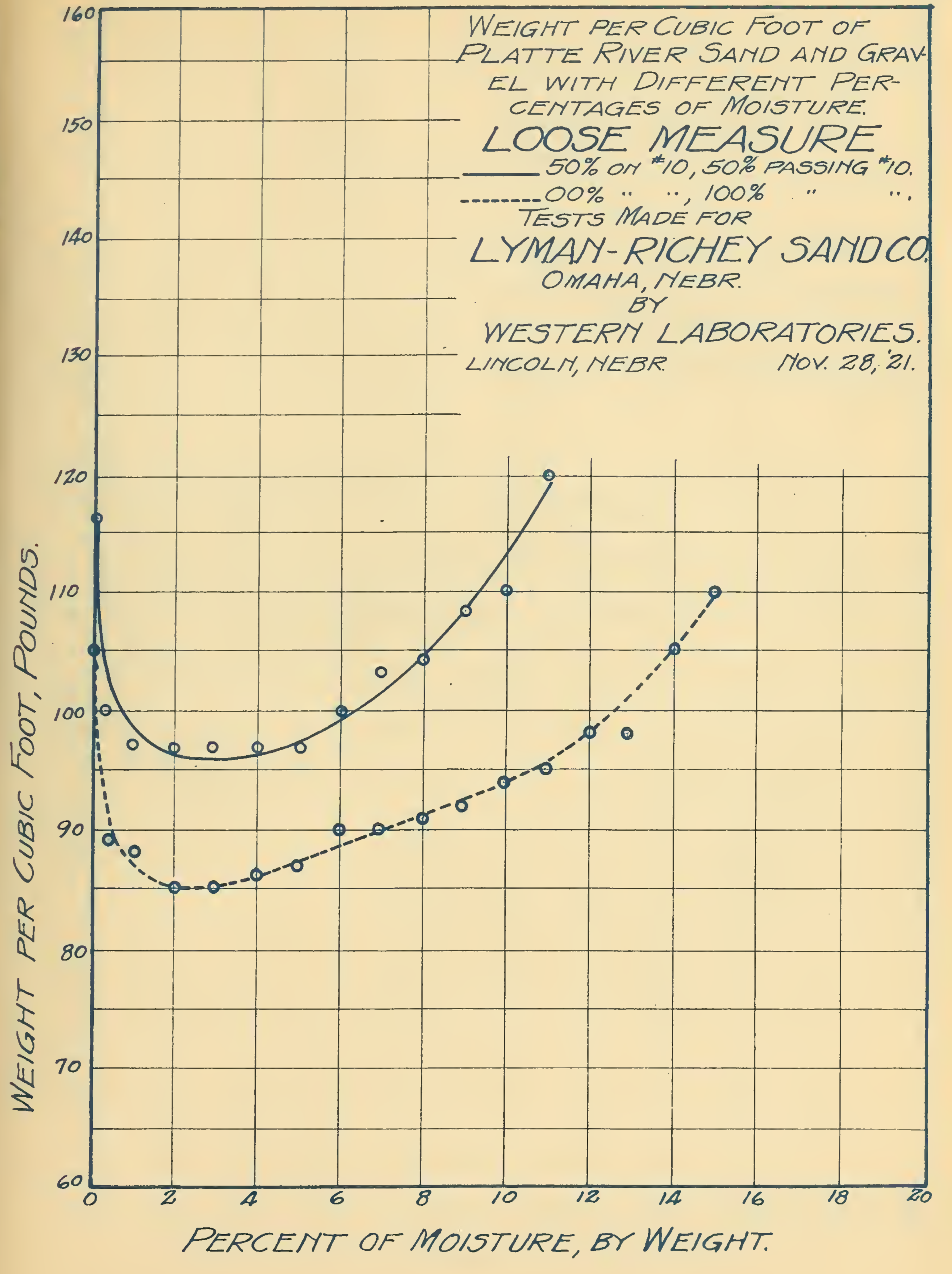
In making the tests herein described the foregoing process was used and in addition determinations were made on the material when in a loose condition, the container being filled without any compaction whatever.

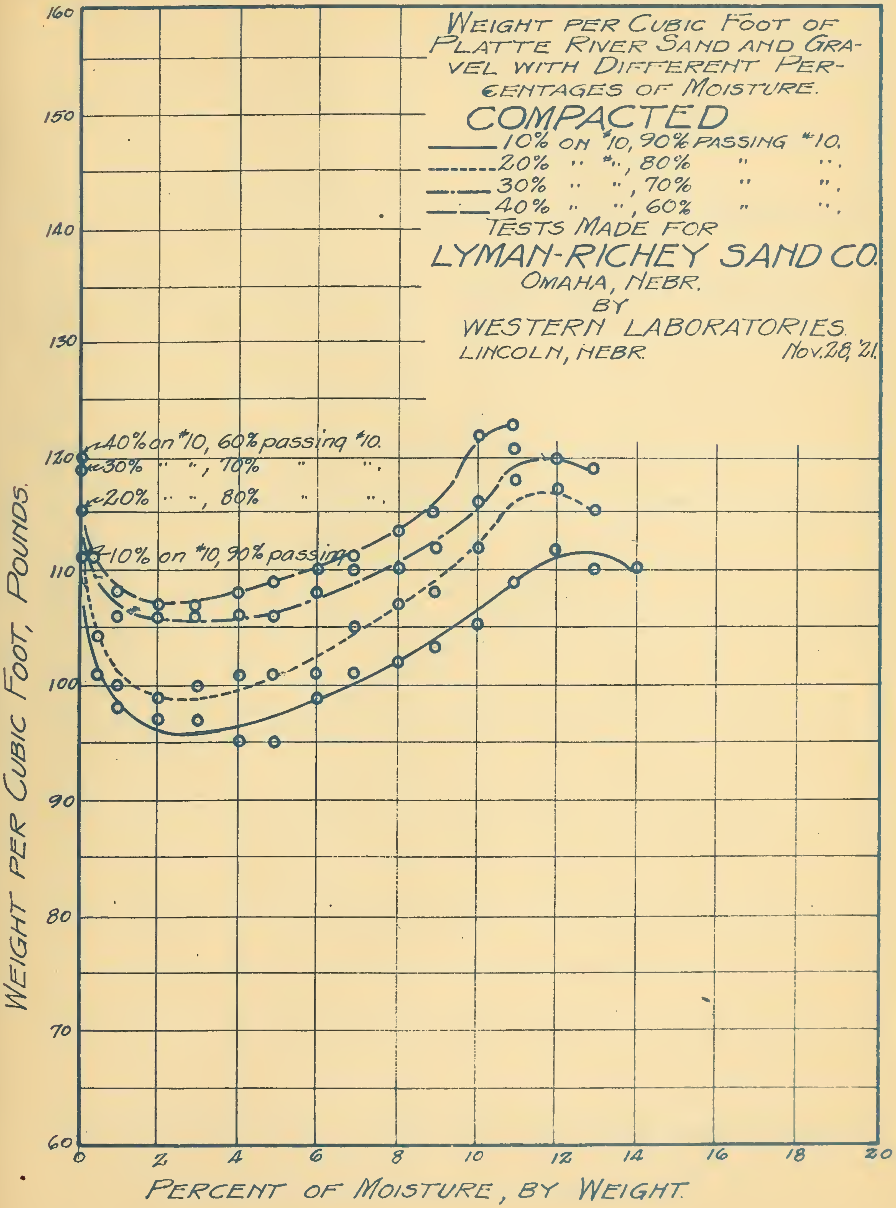
RESULTS OF DETERMINATIONS OF UNIT WEIGHT OF AGGREGATE.

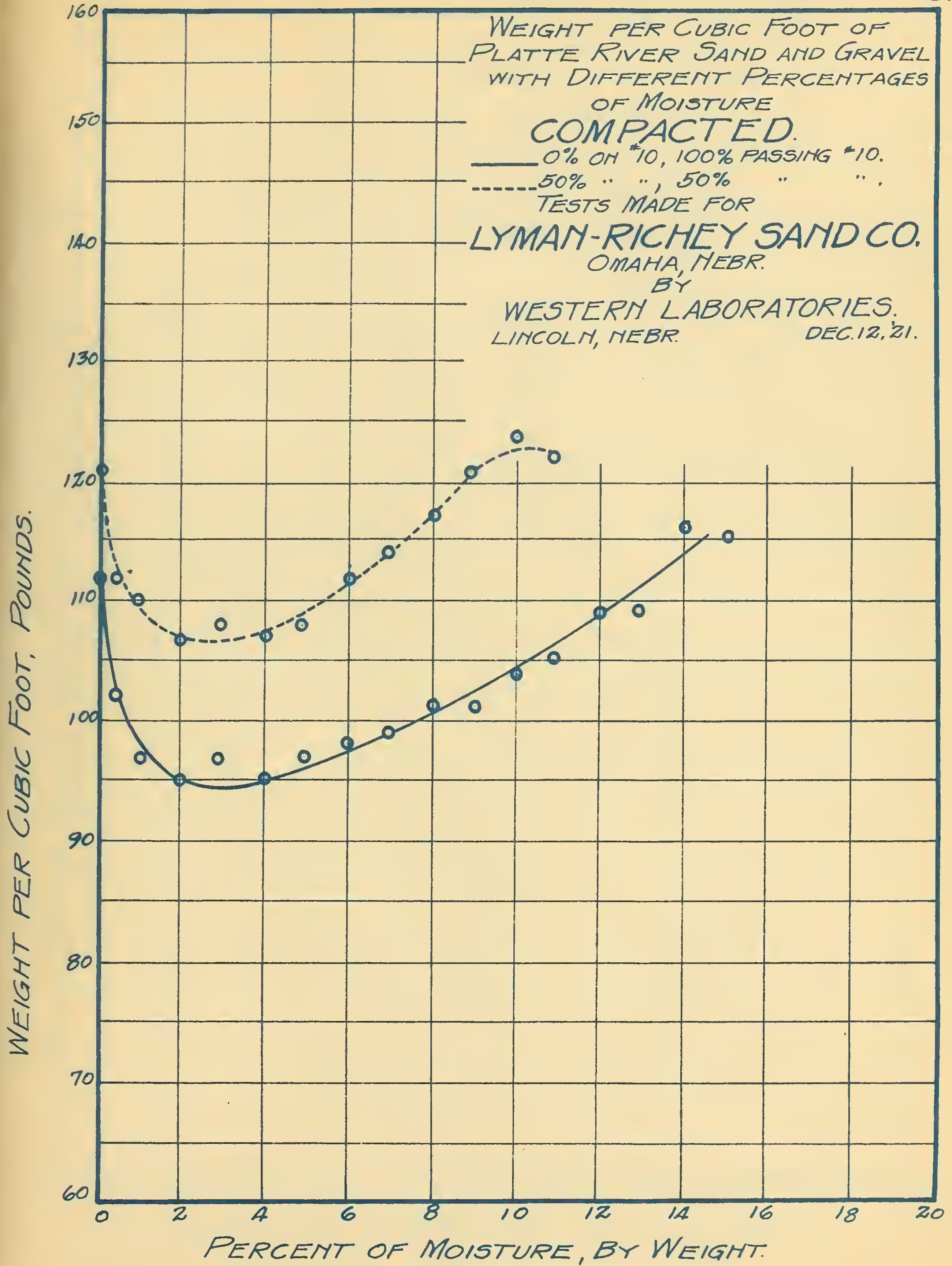
The following curves show the weight per cubic foot of different combinations of sand and gravel from the Platte and Loup Valleys (Columbus) when the percentage of moisture was varied through a wide range. The following proportions of sand and gravel were used in making these tests.

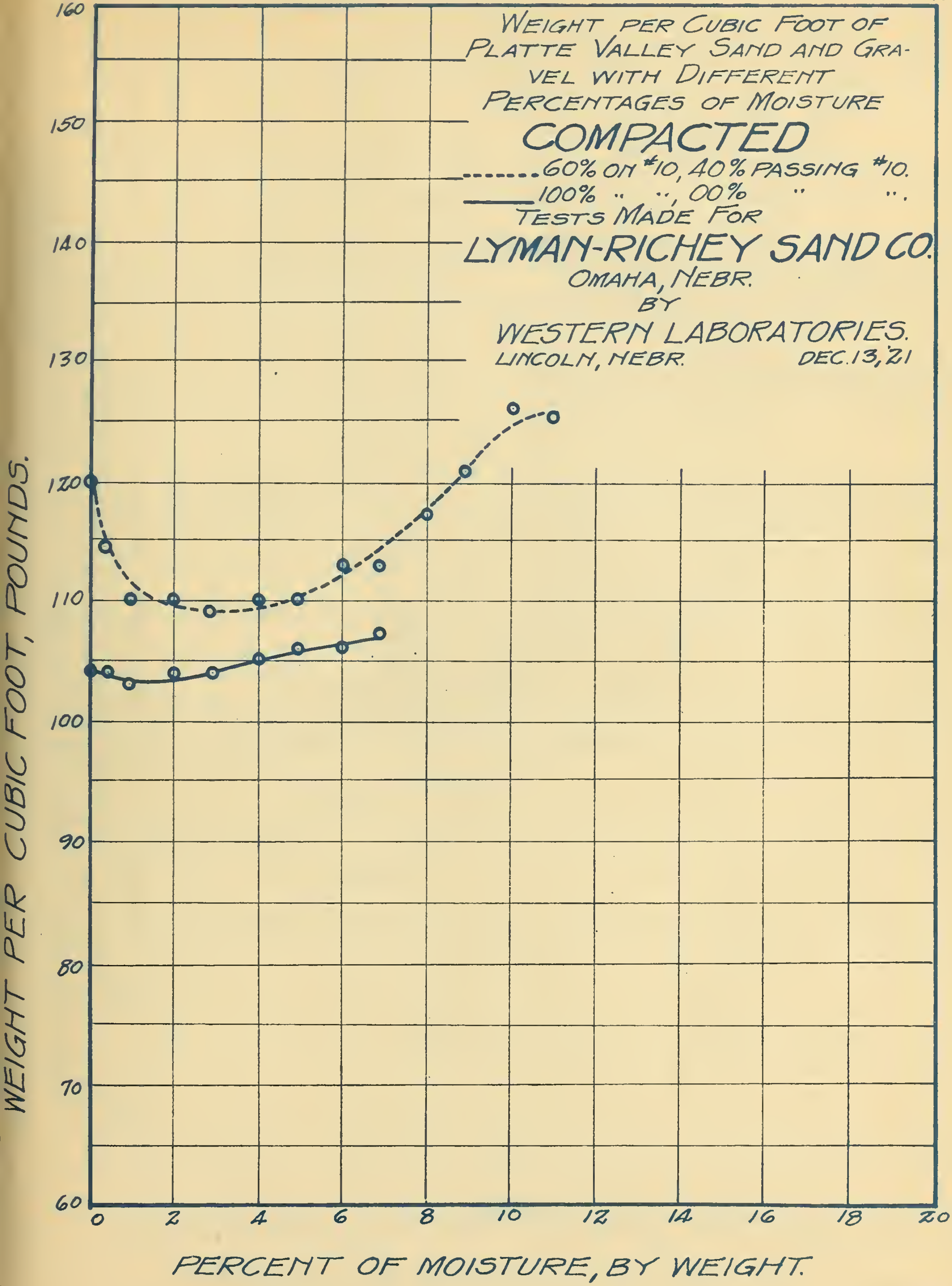

WEIGHT PER CUBIC FOOT OF
PLATTE RIVER SAND AND GRAVEL
WITH DIFFERENT PERCENTAGES OF MOISTURE.
LOOSE MEASURE
10% ON #10, 90% PASSING #10.
20% " ", 80% " ".
30% " ", 70% " ".
40% " ", 60% " ".
TESTS MADE FOR.
LYMAN-RICHEY SAND CO.
OMAHA, NEBR.
BY
WESTERN LABORATORIES.
LINCOLN, NEBR.
NOV. 28, '21.
40% on #10, 60% passing #10.
30% on #10, 70% passing #10.
20% on #10, 80% passing #10.
10% on #10, 90% passing #10.
160
150
140
130
120
110
100
90
80
70
60
0
2
4
6
8
10
12
14
16
18
20
WEIGHT PER CUBIC FOOT, POUNDS.
PERCENT OF MOISTURE, BY WEIGHT.

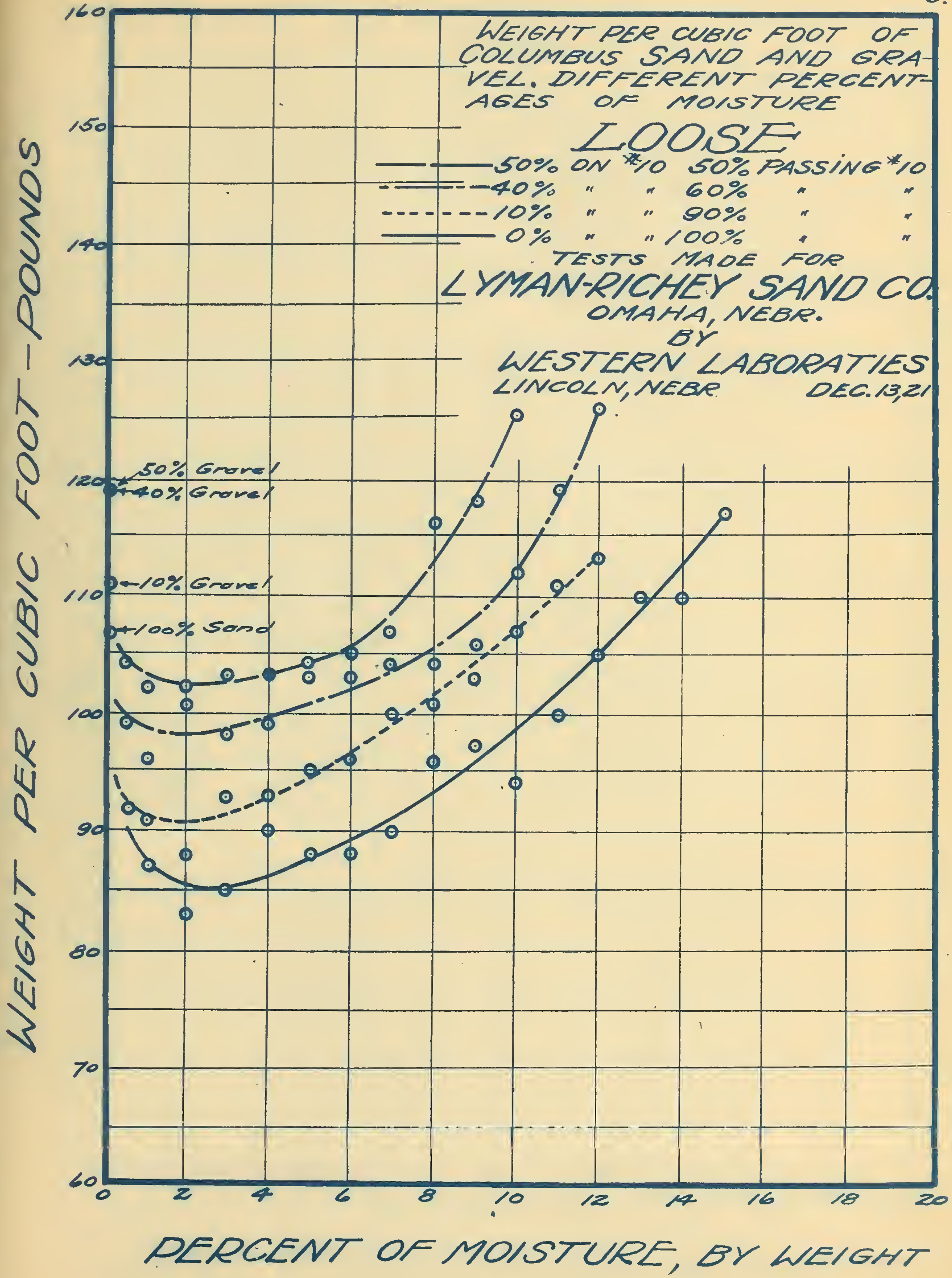

WEIGHT PER CUBIC FOOT OF PLATTE RIVER SAND AND GRAVEL WITH DIFFERENT PERCENTAGES OF MOISTURE.
LOOSE MEASURE.
60% ON #10, 40% PASSING #10.
100% " ", 00% " ".
TESTS MADE FOR
LYMAN-RICHEY SAND CO.
OMAHA, NEBR.
BY
WESTERN LABORATORIES.
LINCOLN, NEBR.
NOV. 28, '21.
160
150
140
130
120
110
100
90
80
70
60
0
2
4
6
8
10
12
14
16
18
20
WEIGHT PER CUBIC FOOT, POUNDS.
PERCENT OF MOISTURE, BY WEIGHT.

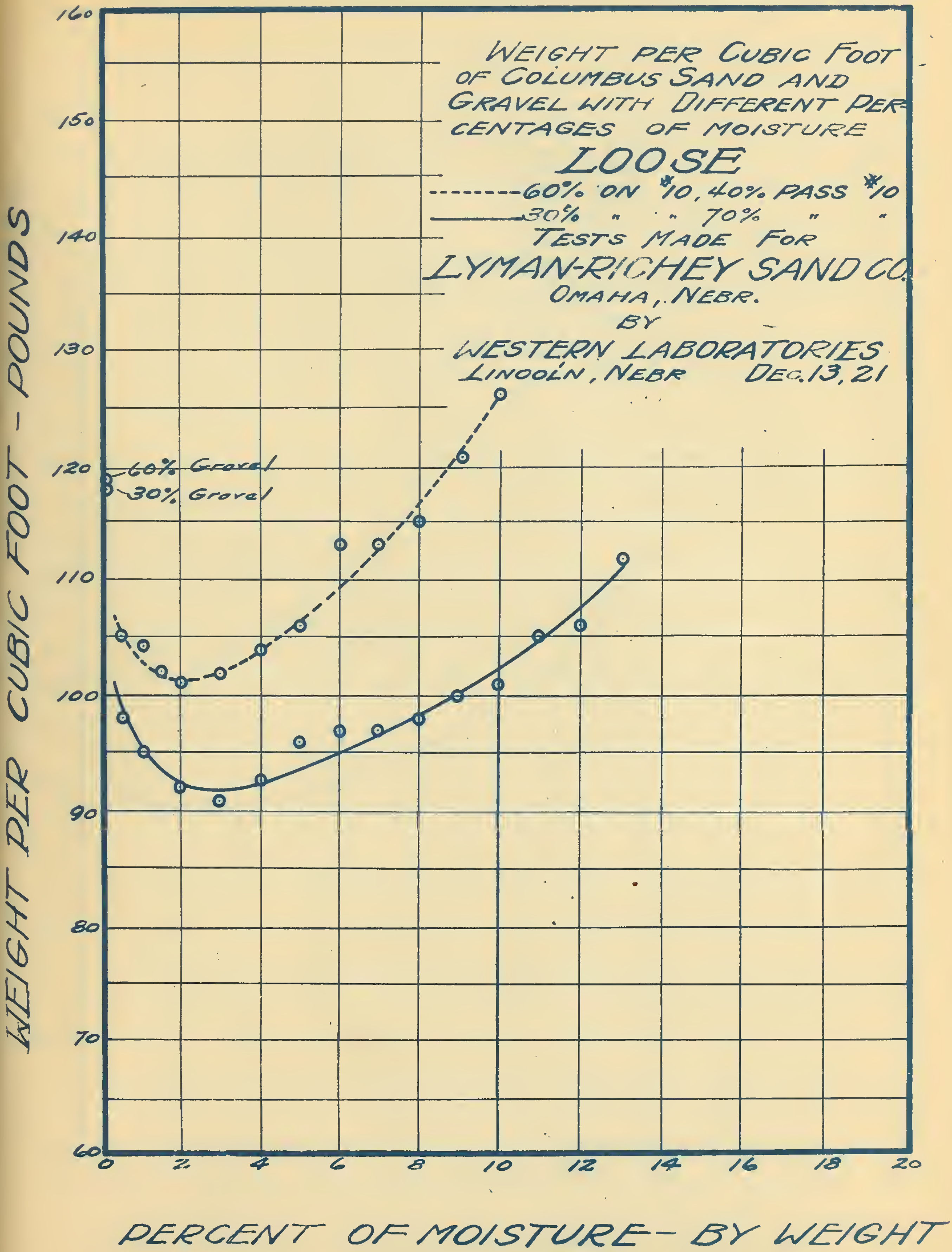

WEIGHT PER CUBIC FOOT OF PLATTE RIVER SAND AND GRAVEL WITH DIFFERENT PERCENTAGES OF MOISTURE.
LOOSE MEASURE
50% ON #10, 50% PASSING #10.
00% " ", 100% " ".
TESTS MADE FOR
LYMAN-RICHEY SAND CO.
OMAHA, NEBR.
BY
WESTERN LABORATORIES.
LINCOLN, NEBR.
NOV. 28, '21.
WEIGHT PER CUBIC FOOT, POUNDS.
PERCENT OF MOISTURE, BY WEIGHT.
160
150
140
130
120
110
100
90
80
70
60
0
2
4
6
8
10
12
14
16
18
20

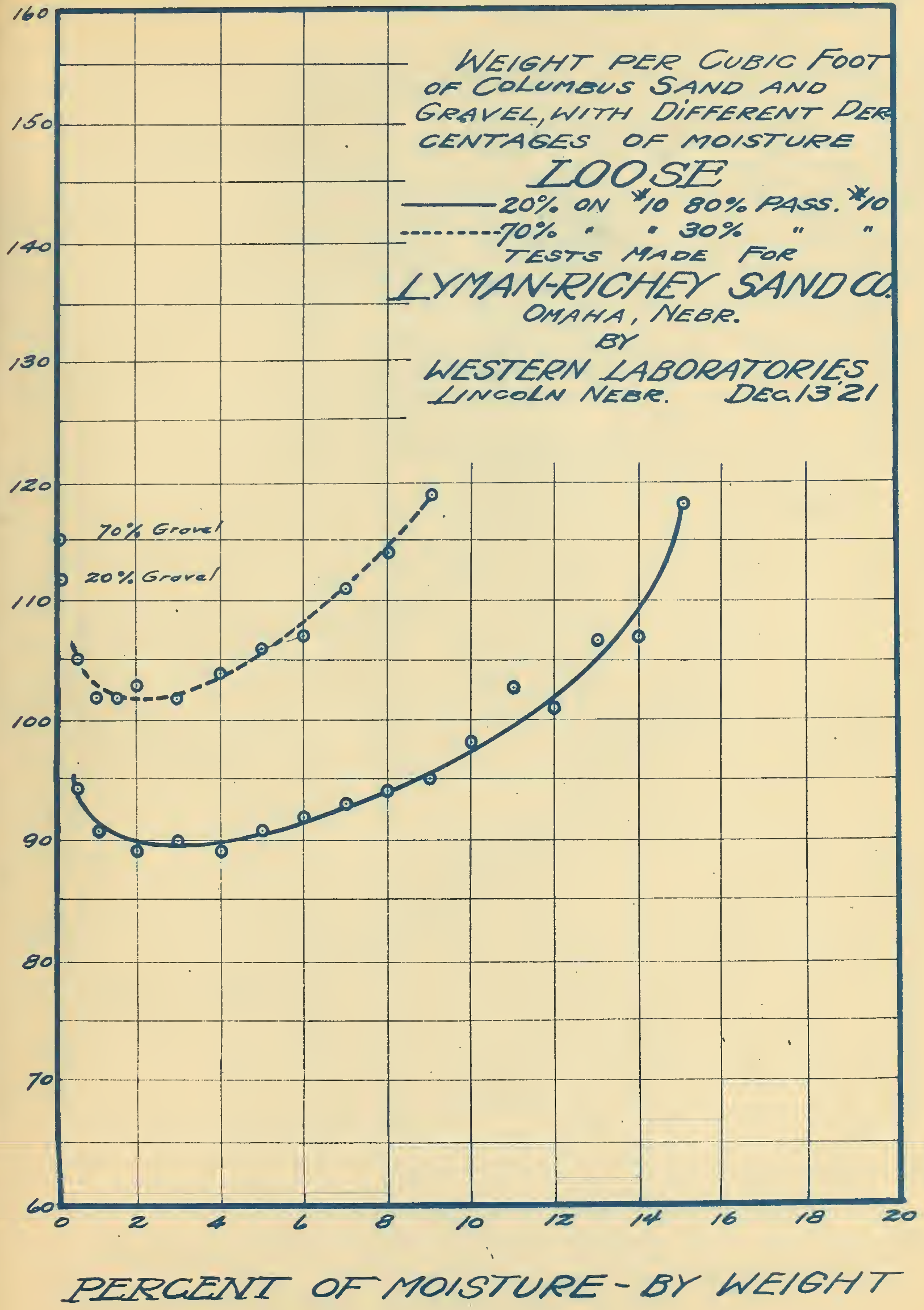

WEIGHT PER CUBIC FOOT OF PLATTE RIVER SAND AND GRAVEL WITH DIFFERENT PERCENTAGES OF MOISTURE.
COMPACTED
10% ON #10, 90% PASSING #10.
20% " #", 80% " ".
30% " ", 70% " ".
40% " ", 60% " ".
TESTS MADE FOR
LYMAN-RICHEY SAND CO.
OMAHA, NEBR.
BY
WESTERN LABORATORIES.
LINCOLN, NEBR.
Nov. 28, '21.
40% on #10, 60% passing #10.
30% " ", 70% " ".
20% " ", 80% " ".
10% on #10, 90% passing
WEIGHT PER CUBIC FOOT, POUNDS.
PERCENT OF MOISTURE, BY WEIGHT.
160
150
140
130
120
110
100
90
80
70
60
0
2
4
6
8
10
12
14
16
18
20

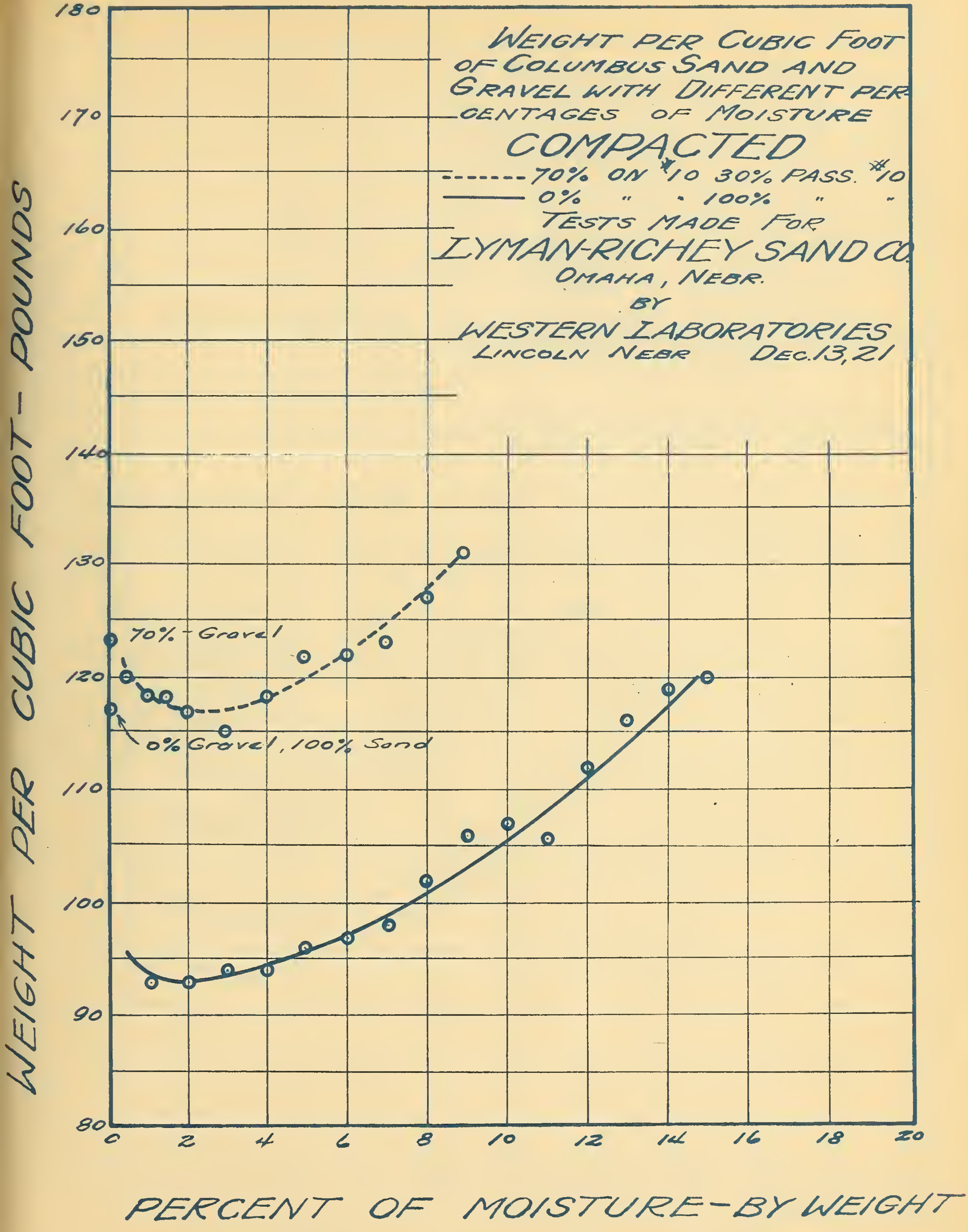

WEIGHT PER CUBIC FOOT OF
PLATTE RIVER SAND AND GRAVEL
WITH DIFFERENT PERCENTAGES
OF MOISTURE
COMPACTED.
0% ON #10, 100% PASSING #10.
50% " ", 50% " ".
TESTS MADE FOR
LYMAN-RICHEY SAND CO.
OMAHA, NEBR.
BY
WESTERN LABORATORIES.
LINCOLN, NEBR.
DEC. 12, '21.
WEIGHT PER CUBIC FOOT, POUNDS.
160
150
140
130
120
110
100
90
80
70
60
0
2
4
6
8
10
12
14
16
18
20
PERCENT OF MOISTURE, BY WEIGHT.


WEIGHT PER CUBIC FOOT OF PLATTE VALLEY SAND AND GRAVEL WITH DIFFERENT PERCENTAGES OF MOISTURE
COMPACTED
------ 60% ON #10, 40% PASSING #10.
—— 100% " ", 00% " ".
TESTS MADE FOR
LYMAN-RICHEY SAND CO.
OMAHA, NEBR.
BY
WESTERN LABORATORIES.
LINCOLN, NEBR. DEC. 13, '21
WEIGHT PER CUBIC FOOT, POUNDS.
160
150
140
130
120
110
100
90
80
70
60
0
2
4
6
8
10
12
14
16
18
20
PERCENT OF MOISTURE, BY WEIGHT.

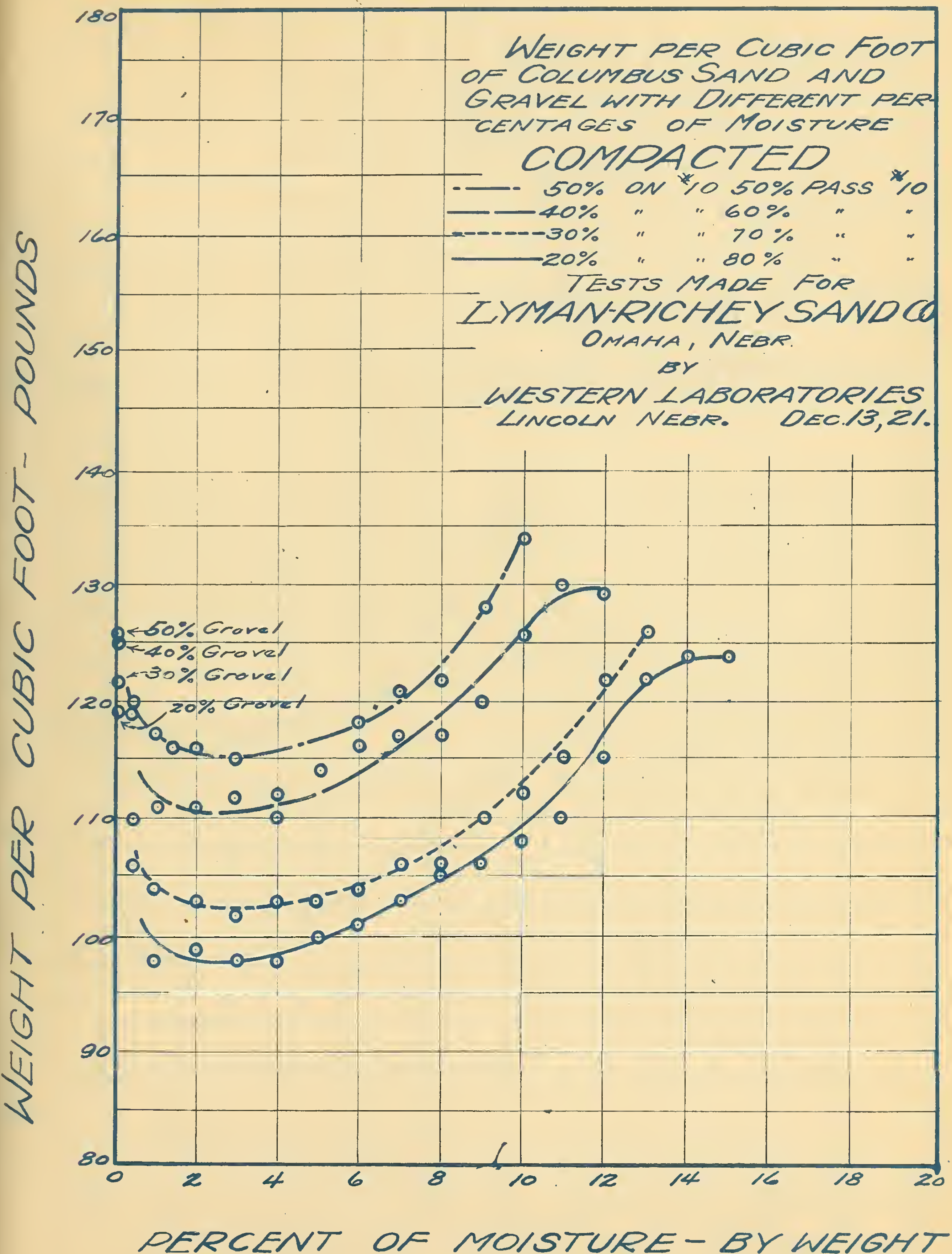

WEIGHT PER CUBIC FOOT OF COLUMBUS SAND AND GRAVEL. DIFFERENT PERCENTAGES OF MOISTURE
LOOSE
50% ON #10 50% PASSING #10
40% " " 60% " "
10% " " 90% " "
0% " " 100% " "
TESTS MADE FOR
LYMAN-RICHEY SAND CO.
OMAHA, NEBR.
BY
WESTERN LABORATIES
LINCOLN, NEBR
DEC. 13, 21
50% Gravel
40% Gravel
10% Gravel
100% Sand
WEIGHT PER CUBIC FOOT - POUNDS
PERCENT OF MOISTURE, BY WEIGHT
160
150
140
130
120
110
100
90
80
70
60
0
2
4
6
8
10
12
14
16
18
20

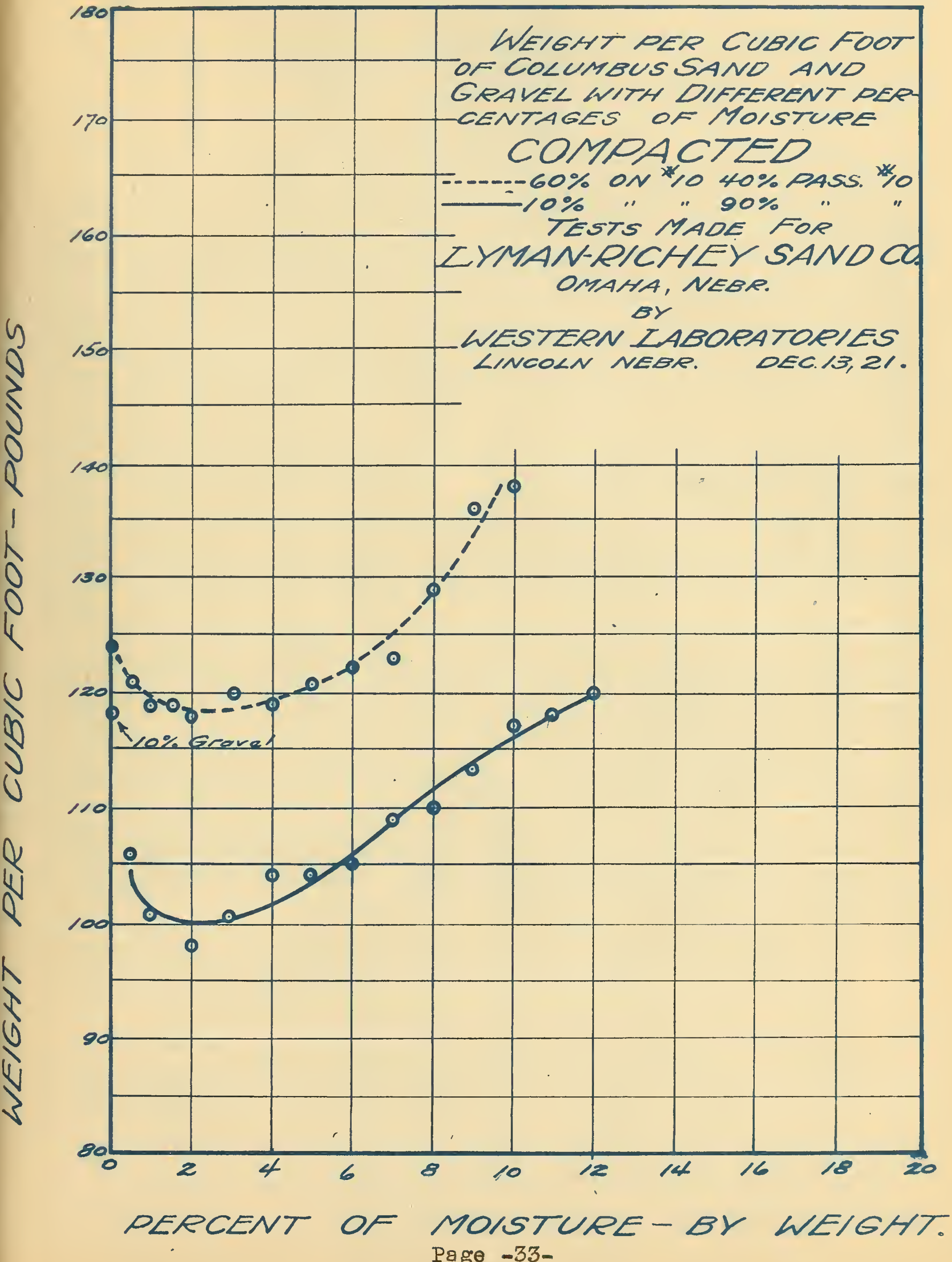

WEIGHT PER CUBIC FOOT OF COLUMBUS SAND AND GRAVEL WITH DIFFERENT PERCENTAGES OF MOISTURE
LOOSE
--------60% ON #10, 40% PASS #10
———30% " " 70% " "
TESTS MADE FOR
LYMAN-RICHEY SAND CO.
OMAHA, NEBR.
BY
WESTERN LABORATORIES
LINCOLN, NEBR DEC. 13, 21
60% Gravel
30% Gravel
WEIGHT PER CUBIC FOOT - POUNDS
PERCENT OF MOISTURE - BY WEIGHT
160
150
140
130
120
110
100
90
80
70
60
0
2
4
6
8
10
12
14
16
18
20


WEIGHT PER CUBIC FOOT OF COLUMBUS SAND AND GRAVEL, WITH DIFFERENT PERCENTAGES OF MOISTURE
LOOSE
20% ON #10 80% PASS. #10
70% " " 30% " "
TESTS MADE FOR
LYMAN-RICHEY SAND CO.
OMAHA, NEBR.
BY
WESTERN LABORATORIES
LINCOLN NEBR. DEC. 13'21
70% Gravel
20% Gravel
160
150
140
130
120
110
100
90
80
70
60
0
2
4
6
8
10
12
14
16
18
20
PERCENT OF MOISTURE - BY WEIGHT



WEIGHT PER CUBIC FOOT OF COLUMBUS SAND AND GRAVEL WITH DIFFERENT PERCENTAGES OF MOISTURE
COMPACTED
70% ON #10 30% PASS. #10
0% " " 100% " "
TESTS MADE FOR
LYMAN-RICHEY SAND CO.
OMAHA, NEBR.
BY
WESTERN LABORATORIES
LINCOLN NEBR DEC. 13, 21
70% - Gravel
0% Gravel, 100% Sand
WEIGHT PER CUBIC FOOT - POUNDS
PERCENT OF MOISTURE - BY WEIGHT
180
170
160
150
140
130
120
110
100
90
80
0
2
4
6
8
10
12
14
16
18
20


WEIGHT PER CUBIC FOOT OF COLUMBUS SAND AND GRAVEL WITH DIFFERENT PERCENTAGES OF MOISTURE
COMPACTED
50% ON #10 50% PASS #10
40% " " 60% " "
30% " " 70% " "
20% " " 80% " "
TESTS MADE FOR
LYMAN-RICHEY SAND CO.
OMAHA, NEBR.
BY
WESTERN LABORATORIES
LINCOLN NEBR. DEC. 13, 21.
50% Gravel
40% Gravel
30% Gravel
20% Gravel
WEIGHT PER CUBIC FOOT - POUNDS
PERCENT OF MOISTURE - BY WEIGHT
180
170
160
150
140
130
120
110
100
90
80
0
2
4
6
8
10
12
14
16
18
20


WEIGHT PER CUBIC FOOT OF COLUMBUS SAND AND GRAVEL WITH DIFFERENT PERCENTAGES OF MOISTURE
COMPACTED
60% ON #10 40% PASS. #10
10% " " 90% " "
TESTS MADE FOR
LYMAN-RICHEY SAND CO.
OMAHA, NEBR.
BY
WESTERN LABORATORIES
LINCOLN NEBR. DEC. 13, 21.
10% Gravel
180
170
160
150
140
130
120
110
100
90
80
0
2
4
6
8
10
12
14
16
18
20
WEIGHT PER CUBIC FOOT - POUNDS
PERCENT OF MOISTURE - BY WEIGHT.

Sand, Passing 10-mesh Sieve, Percentage.	Gravel, Retained on 10-mesh Sieve Percentage.
90%	10%
80%	20%
70%	30%
60%	40%
50%	50%
40%	60%

As an illustration of the results obtained by these determinations it was found that for a material having 80% passing and 20% retained on the 10-mesh sieve (approximately pit-run) the weight per cubic foot loose and dry was found to be 109# for Platte Valley material and 112# for Columbus material. The weights per cubic foot for the same materials dry and compacted, as described above, were 115# and 119# respectively. The weights per cubic foot, loose measure, for the same materials when swelled to their greatest volume by the addition of approximately 3%, by weight, of moisture were 89# and 90# respectively. In other words, in the case of the Platte Valley material there were 115# of gravel to the cubic foot, compacted, as compared with 86# of sand and gravel per cubic foot when loose and containing 3%, by weight, of moisture. In the case of the Columbus material there were 119# of material per cubic foot of dry and compacted aggregate as compared with only 87# of moist material. In other words, there was actually 33.7% more Platte Valley material in the dry compacted measure than when loose and moist. In the case of the Columbus material there was 36.8% more material.

Comparing sand-gravel, that is material having 50% passing and 50% retained on the 10-mesh sieve, it was found that the dry and compacted material weighed 121# per cubic foot in the case of the Platte Valley material and 126# in the case of the Columbus material. When moistened with approximately 3% of water, by weight, the same materials weighed 96# and 102# per cubic foot respectively. In other words, with the Platte Valley material there were 121# of aggregate, compacted, as compared with 93# per cubic foot when loose and containing 3%, by weight, of moisture. In the case of the Columbus material there were 126# of material per cubic foot of dry and compacted aggregate as compared with 99# of sand and gravel per cubic foot when loose and containing 3%, by weight, of moisture. In other words, there was actually 30.1% more Platte Valley material in the dry compacted measure than the loose moist material. In the case of the Columbus material there was 27.4% more material.

SPECIFYING PROPORTIONS BY VOLUME. In view of the fact that there is as much as 36.8% difference in the actual amount of sand and gravel in a unit volume, for certain commercial combinations, dependent upon the method of measurement which is used, and since there is practically always at least 25% difference for any commercial Nebraska sand and gravel it should be apparent that it is impractical to specify the proportions of the concrete mixture by volume only, without further explanation including a statement of the minimun amount of cement allowable per unit volume of concrete, IN PLACE, and expect these specifications to be complied with in the field

without working an injustice on one party to the contract. In order to be sure that the correct amount of cement is being used it is absolutely necessary to make the measurement in place because the volume of the aggregate changes so rapidly with changes in moisture content, as can be seen by an inspection of the curves for "Weight per Cubic Foot". Since a small change in moisture content produces a great change in volume and since the amount of moisture in the aggregate is never known at the time the measurements are made on the work it is absolutely impossible to be sure of obtaining the correct volumes by measurement. The volume should be approximated at the beginning of each piece of work, and afterwards checked in place, and future quantities of materials based upon such measurements.

The advantages to this method are that it makes it possible for all contractors to bid on work with the definite knowledge of exactly how much cement is expected. It also makes it possible to obtain the desired amount of cement in the work without causing friction between the inspector and the contractor's foreman relative to the proper method of determining the amount of aggregate that should be used.#

CONCRETE YIELD. Since there is such a great difference in the amount of aggregate contained in a unit volume of material as the result of a change in moisture content the resulting yield of concrete is greatly influenced by the condition of the aggregate at the time it enters the mixture. When the concrete is mixed to a given consistency, however, there is a certain weight of aggregate per unit volume of concrete regardless of the moisture contained in the aggregate at the beginning. Tests for yield were made upon concrete mixed to consistencies such that the fresh mixture showed a slump of from 1/2" to 1-1/2" and from 5" to 7". The following table shows the yield of concrete per unit volume of aggregate.

#To the writers knowledge, this method of specification was first used in Nebraska on pavement work by Mr. H. H. Tracy, City Engineer, Norfolk, Nebraska.

CONCRETE YIELD FOR NEBRASKA SAND AND GRAVEL COMBINATIONS.

Aggregate Retained on 10-mesh Sieve.	Mix, Parts by Volume.	Approximate Slump, Inches.	Cubic Feet of Concrete from One Cubic Foot of Aggregate. Dry Compacted. Columbus.	Dry Compacted. Platte Valley.	Dry Loose. Columbus.	Dry Loose. Platt Valley.	Wet Loose. Columbus.	Wet Loose. Platte Valley.
10%	1:3	1	1:22	1.10	1.15	1.05	.91	.80
10%	1:3	6	1.23	1.14	1.16	1.09	.92	.84
10%	1:4	1	1.16	1.07	1.09	1.01	.86	.78
10%	1:4	6	1.18	1.10	1.11	1.05	.88	.80
10%	1:5	1	1.13	1.05	1.07	1.01	.85	.79
10%	1:5	6	1:16	1.10	1.09	1.05	.86	.78
10%	1:6	1	1.13	1.07	1.07	1.02	.85	.77
10%	1:6	6	1.13	1.09	1.07	1.04	.85	.78
10%	1:7	1	1.13	1.07	1.07	1.02	.85	.79
10%	1:7	6	1.13	1.08	1.07	1.03	.85	.80
20%	1:3	1		1.15		1.09		.85
20%	1:3	6		1.17		1.11		.87
20%	1:4	1		1.12		1.06		.83
20%	1:4	6		1.14		1.08		.84
20%	1:5	1		1.08		1.03		.80
20%	1:5	6		1.10		1.05		.82
20%	1:6	1		1.07		1.02		.79
20%	1:6	6		1.08		1.03		.80
20%	1:7	1		1.06		1.01		.79
20%	1:7	6		1.08		1.03		.81
30%	1:3	1	1.18	1.15	1.15	1.09	.85	.87
30%	1:3	6	1.21	1.19	1.17	1.12	.87	.90
30%	1:4	1	1.14	1.12	1.10	1.06	.82	.85
30%	1:4	6	1.16	1.14	1.12	1.08	.84	.87
30%	1:5	1	1.11	1.10	1.07	1.04	.80	.84
30%	1:5	6	1.13	1.12	1.09	1.06	.82	.85
30%	1:6	1	1.10	1.09	1.06	1.03	.79	.83
30%	1:6	6	1.10	1.10	1.06	1.04	.80	.83
30%	1:7	1	1.09	1.09	1.05	1.03	.79	.83
30%	1:7	6	1.10	1.10	1.06	1.04	.79	.83
40%	1:3	1	1.18	1.14	1.12	1.09	.91	.88
40%	1:3	6	1.21	1.15	1.16	1.11	.93	.89
40%	1:4	1	1.14	1.11	1.08	1.05	.87	.85
40%	1:4	6	1.15	1.12	1.09	1.07	.88	.86
40%	1:5	1	1.10	1.07	1.04	1.02	84	.83
40%	1:5	6	1.13	1.08	1.07	1.03	.86	.83
40%	1:6	1	1.10	1.04	1.04	.99	.84	.80
40%	1:6	6	1.12	1.07	1.06	1.02	.86	.82
40%	1:7	1	1.08	1.04	1.03	.99	.83	.80
40%	1:7	6	1.10	1.05	1.04	1.00	.84	.81

CONCRETE YIELD FOR NEBRASKA SAND AND GRAVEL COMBINATIONS.

Aggregate Retained on 10-mesh Sieve.	Mix, Parts by Volume.	Approximate Slump, Inches.	Cubic Feet of Concrete from One Cubic Foot of Aggregate. Dry Compacted. Columbus.	Dry Compacted. Platte Valley.	Dry Loose. Columbus.	Dry Loose. Platt Valley.	Wet Loose. Columbus.	Wet Loose. Platte Valley.
50%	1:3	1	1:18	1.11	1.11	1.06	.93	.85
50%	1:3	6	1.19	1.15	1.12	1.10	.94	.89
50%	1:4	1	1.13	1.07	1.07	1.03	.90	.83
50%	1:4	6	1.15	1.10	1.08	1.05	.91	.85
50%	1:5	1	1.09	1.04	1.03	1.00	.86	.80
50%	1:5	6	1:10	1.06	1.04	1.02	.88	.82
50%	1:6	1	1.06	1.05	1.00	1.00	.84	.81
50%	1:6	6	1.09	1.07	1.03	1.02	.86	.82
50%	1:7	1	1.05	1.06	.99	1.01	.83	.81
50%	1:7	6	1.08	1.06	1.02	1.01	.85	.81
60%	1:3	1	1.14	1.10	1.09	1.03	.91	.85
60%	1:3	6	1.17	1.12	1.12	1.05	.93	.87
60%	1:4	1	1.08	1.04	1.03	.97	.86	.81
60%	1:4	6	1.09	1.08	1.04	1.01	.87	.83
60%	1:5	1	1.04	1.02	1.00	.95	.83	.79
60%	1:5	6	1.07	1.04	1.03	.97	.85	.81
60%	1:6	1	1.02	1.01	.98	.94	.82	.78
60%	1:6	6	1.05	1.03	1.01	.97	.84	.80
60%	1:7	1	.99	1.03	.94	.96	.79	.80
60%	1:7	6	1.01	1.03	.96	.96	.80	.80

CONCRETE YIELD FOR COMBINATIONS OF ONE INCH BROKEN STONE AND PIT-RUN SAND AGGREGATE.

Mix, Parts by Volume.	Approximate Slump, Inches.	Cubic Feet of Concrete from One Cubic Foot of Combined Sand and Stone Aggregate. Dry Compacted.	Dry Loose
1:2:3	1	1.05	1.05
1:2:3	6	1.08	1.08
1:2:3-1/2	1	1.02	1.00
1:2:3-1/2	6	1.05	1.03
1:2:4	1	.99	.98
1:2:4	6	1.01	.99
1:2-1/2:4	1	.98	.97
1:2-1/2:4	6	1.00	.99
1:2-1/2:5	1	.98	.97
1:2-1/2:5	6	.98	.97
1:3:5	1	1.01	.99
1:3:5	6	1.02	1.00
1:3:6	1	.96	.95
1:3:6	6	.98	.96
1:4:5-1/2	1	1.02	1.00
1:4:5-1/2	6	1.02	1.00

It will be noticed that the concrete yield for the finer aggregates is greater than for the coarser materials. The yield is also greater for the richer mixtures. This is the natural result of the fact that the moisture swells the finer aggregate to a greater extent than the coarser materials and the greater amount of cement will, of course, increase the bulk of concrete if there is more than enough to fill the voids in the aggregate.

For most grades of material and proportions of cement and aggregate the yield of concrete is about the same as the volume of aggregate used, when measured dry and loose. In other words, if the mixture is to be made on a volume basis it should be based upon the dry loose volume of aggregate.

It is also interesting to notice that if the mixture is made on a basis of wet loose material that the shrinkage may be as great as 20%. This emphasizes what has already been brought out, namely, that specifications should not be drawn so as to simply call for a certain volume of cement to aggregate, but should also stipulate the actual amount of cement to be used in each unit volume of concrete in place.

According to the standard definition, "concrete yield" is the volume of concrete produced by one volume of aggregate MIXED AS USED. An inspection of the foregoing tabulation shows that the concrete yield of sand-gravel is greater, for many mixtures and just as great for all mixtures as the yield of an aggregate made up of one-inch stone and pit-run sand.

There has been a general impression among many contractors that the concrete yield produced by an aggregate of broken stone and sand is much greater than for sand-gravel materials, for two reasons. First, the volume of the sand-gravel used has been measured in a moist and loose condition, when the bulk is the greatest, The material will naturally show a shrinkage from that condition when afterwards measured, in place, in concrete. Second, the volume of the stone aggregate is taken as the original volume of material, rather than the volume of the mixed stone and sand, which should be used for comparison. The foregoing table shows the correct yield of a broken-stone (1" stone) and sand aggregate. The following table shows the erroneous conclusions that may be drawn in this connection, if the volume of the stone is taken as the original volume of the aggregate entering into a broken-stone-sand aggregate.

It will be noticed that the optimal yield for the finer aggregates is greater than for the coarser materials. The yield is also greater for the richer mixtures. This is the natural result of the fact that the [illegible] required [illegible] the finer aggregate to a great-er extent than the coarser [illegible] and the greater amount of ce-ment [illegible] of course, [illegible] the bulk of [illegible] is more than enough to fill the voids in the aggregate.

For [illegible] amount of material and proportions of cement and aggregate the yield of concrete is about the same as the volume of aggregate used, [illegible]. In other words, if the [illegible] the volume of concrete [illegible] upon the dry loose volume of aggregate.

It is also interesting to notice that if the mixture is [illegible] [illegible] that the [illegible] may be given as [illegible]. This [illegible] that the [illegible] [illegible], however, that [illegible] should not be [illegible] [illegible] [illegible] [illegible] aggregate [illegible] [illegible] [illegible] [illegible].

According to the [illegible] [illegible] the volume of [illegible] [illegible] of aggregate [illegible]. [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] for all [illegible] of [illegible] [illegible] [illegible].

[illegible] [illegible] [illegible] that the [illegible] [illegible] aggregate [illegible] [illegible] [illegible] greater than [illegible]. [illegible] the volume of [illegible] [illegible] [illegible] [illegible] [illegible] the volume of [illegible] [illegible] [illegible] for [illegible] [illegible] [illegible] [illegible] if the volume of the [illegible] [illegible] aggregate [illegible] [illegible] aggregate.

CUBIC FEET OF CONCRETE PRODUCED FROM ONE CUBIC FOOT OF ONE INCH BROKEN STONE WITH PIT-RUN SAND.

Mix, Parts by Volume.	Approximate Slump, Inches.	Concrete Produced from One Cubic Foot of Stone, Cubic Feet.	Cubic Feet of Sand Used with Each Cubic Foot of Stone.
1:2:3	1	1.33	.66
1:2:3	6	1.37	.66
1:2:3-1/2	1	1.22	.57
1:2:3-1/2	6	1.26	.57
1:2:4	1	1.16	.50
1:2:4	6	1.17	.50
1:2-1/2:4	1	1.18	.63
1:2-1/2:4	6	1.19	.63
1:2-1/2:5	1	1 16	.50
1:2-1/2:5	6	1.15	.50
1:3:5	1	1.25	.60
1:3:5	6	1.26	.60
1:3:6	1	1.13	.50
1:3:6	6	1.13	.50
1:4:5-1/2	1	1.38	.73
1:4:5-1/2	6	1.37	.73

ECONOMY OF SAND GRAVEL AGGREGATE. If the foregoing method of comparison is used it is apparent how erroneous conclusions may be arrived at. However, since concrete aggregates are purchased on a tonnage basis a real comparison of their cost should therefore be based upon the actual weight of material that is necessary for one cubic unit of concrete, in place. The following table shows the actual amount of aggregate per cubic foot of concrete for various mixtures of cement and aggregate and for different grades of material.

POUNDS OF AGGREGATE IN ONE CUBIC FOOT OF SAND AND GRAVEL CONCRETE.

Aggregate Retained on 10-mesh Sieve.	Mix, Parts by Volume.	Approximate Slump, Inches.	Pounds of Aggregate per Cubic Foot of Concrete. Columbus.	Platte Valley.
10%	1:3	1	97	101
10%	1:3	6	96	97
10%	1:4	1	102	105
10%	1:4	6	100	102
10%	1:5	1	104	106
10%	1:5	6	102	101
10%	1:6	1	104	104
10%	1:6	6	104	102
10%	1:7	1	104	104
10%	1:7	6	104	103

POUNDS OF AGGREGATE IN ONE CUBIC FOOT OF SAND AND GRAVEL CONCRETE.

Aggregate Retained on 10-mesh Sieve.	Mix, Parts by Volume.	Approximate Slump, Inches.	Pounds of Aggregate per Cubic Foot of Concrete. Columbus.	Platte Valley.
20%	1:3	1		101
20%	1:3	6		98
20%	1:4	1		103
20%	1:4	6		102
20%	1:5	1		106
20%	1:5	6		104
20%	1:6	1		108
20%	1:6	6		106
20%	1:7	1		108
20%	1:7	6		106
30%	1:3	1	103	103
30%	1:3	6	101	101
30%	1:4	1	107	106
30%	1:4	6	105	105
30%	1:5	1	110	108
30%	1:5	6	108	106
30%	1:6	1	111	109
30%	1:6	6	111	108
30%	1:7	1	112	109
30%	1:7	6	111	108
40%	1:3	1	106	105
40%	1:3	6	103	104
40%	1:4	1	110	109
40%	1:4	6	109	107
40%	1:5	1	114	112
40%	1:5	6	111	111
40%	1:6	1	114	115
40%	1:6	6	112	112
40%	1:7	1	116	116
40%	1:7	6	114	114
50%	1:3	1	107	110
50%	1:3	6	106	106
50%	1:4	1	111	114
50%	1:4	6	110	110
50%	1:5	1	116	116
50%	1:5	6	114	114
50%	1:6	1	119	115
50%	1:6	6	117	114
50%	1:7	1	120	115
50%	1:7	6	118	114

POUNDS OF AGGREGATE IN ONE CUBIC FOOT OF SAND AND GRAVEL CONCRETE.

Aggregate Retained on 10-mesh Sieve.	Mix, Parts by Volume.	Approximate Slump, Inches.	Pounds of Aggregate per Cubic Foot of Concrete. Columbus.	Platte Valley.
60%	1:3	1	109	110
60%	1:3	6	106	108
60%	1:4	1	115	116
60%	1:4	6	114	112
60%	1:5	1	119	119
60%	1:5	6	116	115
60%	1:6	1	121	120
60%	1:6	6	118	116
60%	1:7	1	126	118
60%	1:7	6	124	116

POUNDS OF AGGREGATE IN ONE CUBIC FOOT OF BROKEN-STONE-SAND CONCRETE.

Mix, Parts by Volume.	Approximate Slump, Inches.	Pounds of Aggregate per Cubic Foot of Concrete.		
		One Inch Broken Stone.	Sand.	Total Weight of Aggregate.
1:2:3	1	68	52	120
1:2:3	6	66	51	117
1:2:3-1/2	1	74	49	123
1:2:3-1/2	6	72	47	119
1:2:4	1	79	45	124
1:2:4	6	77	45	122
1:2-1/2:4	1	77	48	125
1:2-1/2:4	6	76	47	123
1:2-1/2:5	1	79	46	125
1:2-1/2:5	6	79	46	125
1:3:5	1	73	54	127
1:3:5	6	72	53	125
1:3:6	1	81	47	128
1:3:6	6	80	46	126
1:4:5-1/2	1	65	60	125
1:4:5-1/2	6	66	59	125

From an inspection of the foregoing tables it is seen that a 1:4 or a 1:5 sand-gravel concrete contains less aggregate than a 1:2:4 broken-stone-sand concrete, and a 1:5 or a 1:6 sand-gravel concrete contains less aggregate than a 1:3:5 or 1:3:6 broken-stone-sand concrete, by weight. In other words, for concretes of equal strength there is actually less aggregate used when sand-gravel is used than when a combination of broken stone and sand is used.

QUANTITIES TO BE USED IN ESTIMATING. In estimating the amount of material which is necessary for aggregate the following blue prints were prepared. The quantities given are such that they include the amount of material, by weight, necessary for any mixture, due allowance being made for all losses which will normally occur.

QUANTITIES OF MATERIAL NECESSARY FOR ESTIMATING CONCRETE MADE FROM NEBRASKA GRAVELS

Tests Made For
LYMAN RICHEY SAND CO.
OMAHA, NEBR.

BY

WESTERN LABORATORIES
LINCOLN, NEBR.

MAR. 3, 1922

Aggregate Retained on 10-Mesh sieve	Mix Parts by Volume	Pounds Necessary to Order for Each Cubic Foot of Concrete			
		PLATTE VALLEY		COLUMBUS	
		Reinforced Concrete	Pavement base	Reinforced Concrete	Pavement base
10%	1:3	106	102	102	101
"	1:4	110	107	107	105
"	1:5	111	106	109	107
"	1:6	109	107	109	109
"	1:7	109	108	109	109
20%	1:3	106	103		
"	1:4	108	107		
"	1:5	111	109		
"	1:6	113	111		
"	1:7	113	111		
30%	1:3	108	106	108	106
"	1:4	111	110	112	110
"	1:5	113	111	116	113
"	1:6	114	113	117	117
"	1:7	114	113	118	117
40%	1:3	110	109	111	108
"	1:4	114	112	116	114
"	1:5	118	117	120	117
"	1:6	121	118	120	118
"	1:7	122	120	122	120
50%	1:3	116	111	112	111
"	1:4	120	115	117	116
"	1:5	122	120	122	120
"	1:6	121	120	125	123
"	1:7	121	120	126	124
60%	1:3	116	113	114	111
"	1:4	122	118	121	120
"	1:5	125	121	125	122
"	1:6	126	122	127	124
"	1:7	124	122	132	130

QUANTITIES OF MATERIAL NECESSARY FOR CONCRETE MADE FROM NEBRASKA 1-INCH CRUSHED ROCK AND PITRUN SAND

TESTS MADE FOR

LYMAN-RICHEY SAND CO.

OMAHA NEBR.

BY

WESTERN LABORATORIES

LINCOLN, NEBR. MAR. 3 1922

Mix Parts by Volume	Pounds Necessary to Order for Each Cubic Foot of Concrete					
	Crushed Rock		Sand		Combined Mix	
	Reinforced Concrete	Pavement Base	Reinforced Concrete	Pavement Base	Reinforced Concrete	Pavement Base
1:2:3	69	67	55	54	124	121
1:2:3½	75	73	51	49	126	121
1:2:4	80	78	47	47	127	125
1:2½:4	78	77	50	49	128	126
1:2½:5	80	80	48	48	128	128
1:3:5	74	73	57	56	131	129
1:3:6	82	81	49	48	131	129
1:4:5½	66	67	63	61	129	128

Conclusions Drawn from a Consideration of the Concrete Yield of Sand-Gravel Combinations.

1. A small percentage of moisture may change the volume of sand-gravel to such an extent that it is increased as much as 30% when measured wet and loose as compared with the same material measured dry and compacted.

2. Specifications should always be so drawn as to stipulate exactly how much cement is required per unit volume of concrete, in place. This is absolutely necessary in order to be fair to both contracting parties, on contract work, and in order to have a definite and fair basis for checking the work.

3. The concrete yield is greater for sand-gravel than for an aggregate made up of one inch stone and sand.

4. The actual weight of aggregate in sand-gravel concrete is less than for concrete made from broken stone and sand, with corresponding strength.